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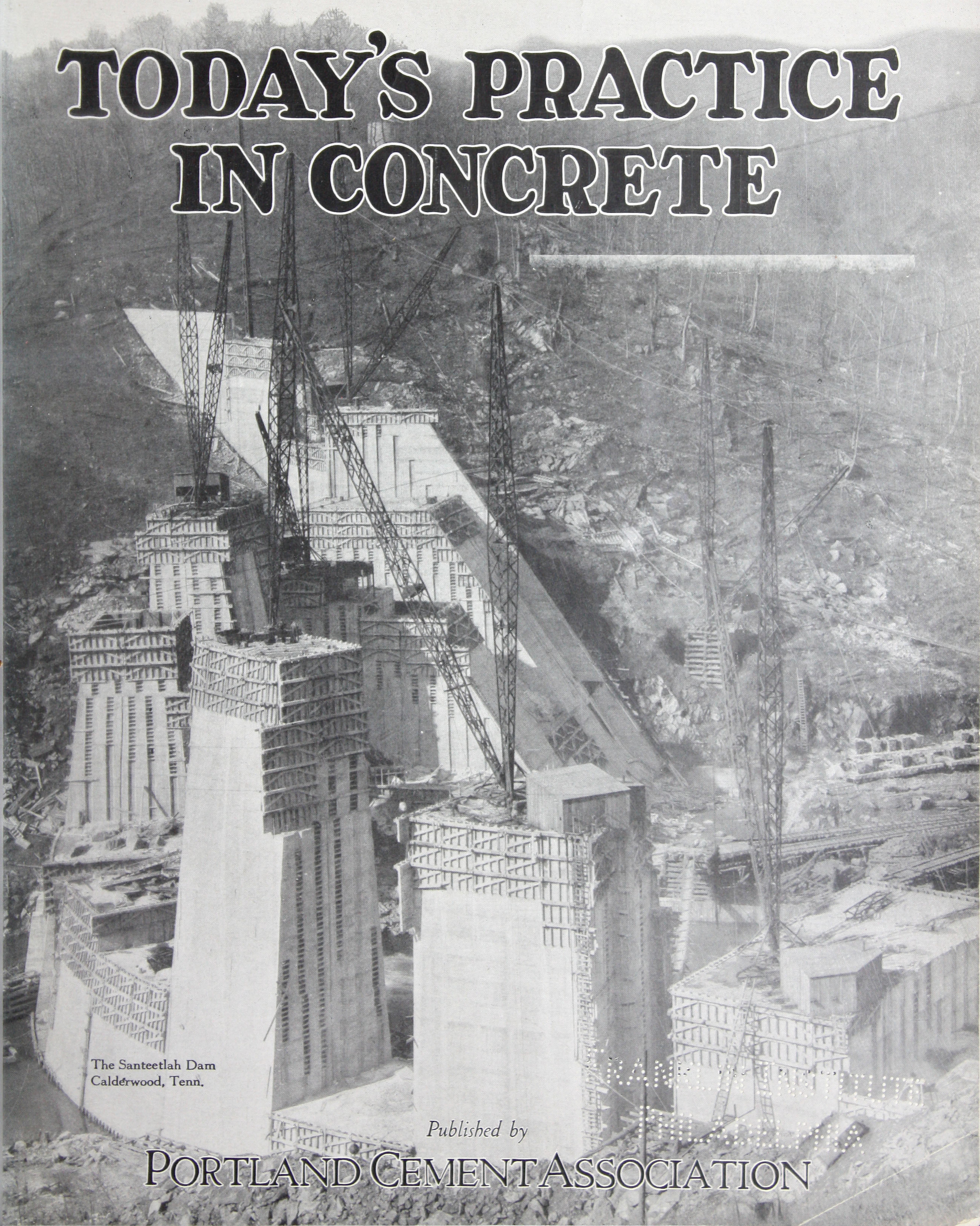
TODAY'S PRACTICE IN CONCRETE



The Santeetlah Dam
Calderwood, Tenn.

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PORTLAND CEMENT ASSOCIATION

FOREWORD

Rapid advances taking place in the construction industries are bringing about notable economies and improvements in quality of finished structures. The general adoption of concrete is one of the greatest advances. Concrete is made by combining suitable mineral aggregates with water and cement and can be used for a large variety of purposes. It is one of the most generally used engineering materials, due to its adaptability to a variety of forms, shapes and conditions. New methods for controlling the manufacture of concrete on the job, introduced several years ago, are being readily applied to field conditions. This has been a matter of development of field practice, many interesting examples of which are contained in this publication.

No attempt is made to supply the complete technology of the methods employed for designing mixtures and controlling the field processes, but the few structures illustrated are examples of the type and variety of structures on which field control has been successfully applied. The principles involved and the methods employed are more fully described in the Portland Cement Association publication "Design and Control of Concrete Mixtures." The latter describes methods of proportioning, field control of concrete, testing of concrete and concreting materials, and gives the standard tests of the American Society for Testing Materials. It also includes a suggested water-cement ratio specification for concrete. Copies are available on request and there is no charge.

Today's Practice in Concrete

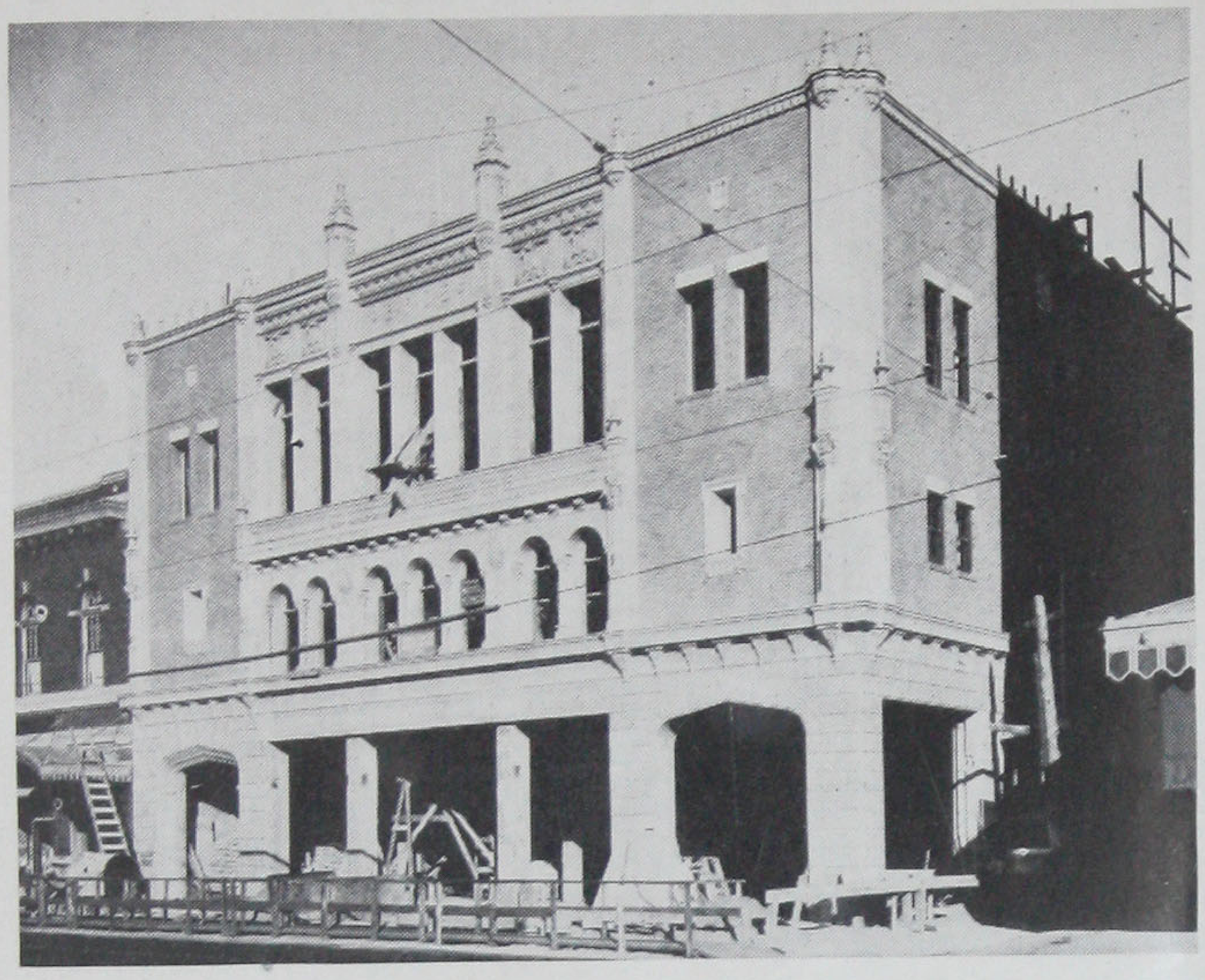
ARCHITECTURAL and engineering specifications of recent years have reflected the change in the conception of methods of making concrete. Old methods have been replaced with new ones to produce concrete with the required strength and durability, conveniently, economically and with increased certainty. These changes are direct results of research work in cement and concrete conducted by a large number of engineering organizations, in both laboratory and field. Concrete is now regarded as a mixture of cement-water paste (which produces the strength of the mixture), to which aggregates are added for economy.

A new era in construction practice has resulted from the recognition of the relation that exists between the strength and other qualities of concrete to the amount of mixing water used. Recognition of this basic principle is perhaps the most significant step in the progress of our knowledge of concrete and concreting materials. Specifications for concrete have been quite generally revised to specify the amount of mixing water to be used or permitted, because of its importance in controlling the strength and other properties of concrete.

The Water-Cement Ratio

Concrete may be considered as an aggregate mass, thoroughly incorporated in a cement-water paste. The properties of this paste, and therefore the properties of the concrete, will be affected in an important degree by the relative proportion of cement and water. Concretes in which a thin, watery paste is used will be less strong than those in which a cement-water paste with low water content is

Coosa River Dam built by the Alabama Power Company. 450,000 cu. yd. of concrete were required for this project. Samples of the materials were sent to the laboratory where the mixes were designed. Slump tests were made frequently as a check of the consistency. Test specimens were made each day that concrete was placed. Three different classes of concrete were specified and the test specimens consistently showed satisfactory results. Similar control methods are being used by this company on all its construction work.



Elks Lodge, Fresno, Calif. This is a reinforced concrete structure with exterior walls of concrete veneered with brick and stone. Two classes of concrete were specified to have minimum strengths of 2000 and 3000 lb. per sq. in. at 28 days. All of the test specimens gave strengths higher than the minimum required with economy in materials. Water was controlled by a specially trained man using a calibrated tank on the mixer. Kump & Johnson, Architects and Engineers; E. H. Mellencamp, Concrete Contractor.

employed. Fortunately, that which is done to improve the strength will in general add to the durability and resistance of the concrete to penetration of water and the effects of weather.

Applying the Water-Cement Ratio

In limiting the amount of water per sack of cement in the specifications, concrete can be made to meet a wide range of requirements of architect and engineer. That such specifications are meeting with their approval is evident from their widespread use. It is impossible to compile a complete list of projects on which the water-cement ratio has been incorporated in the specifications, but a few illustrations will serve to show the permanent place which this principle has secured in construction practice.

Advantages to Contractor

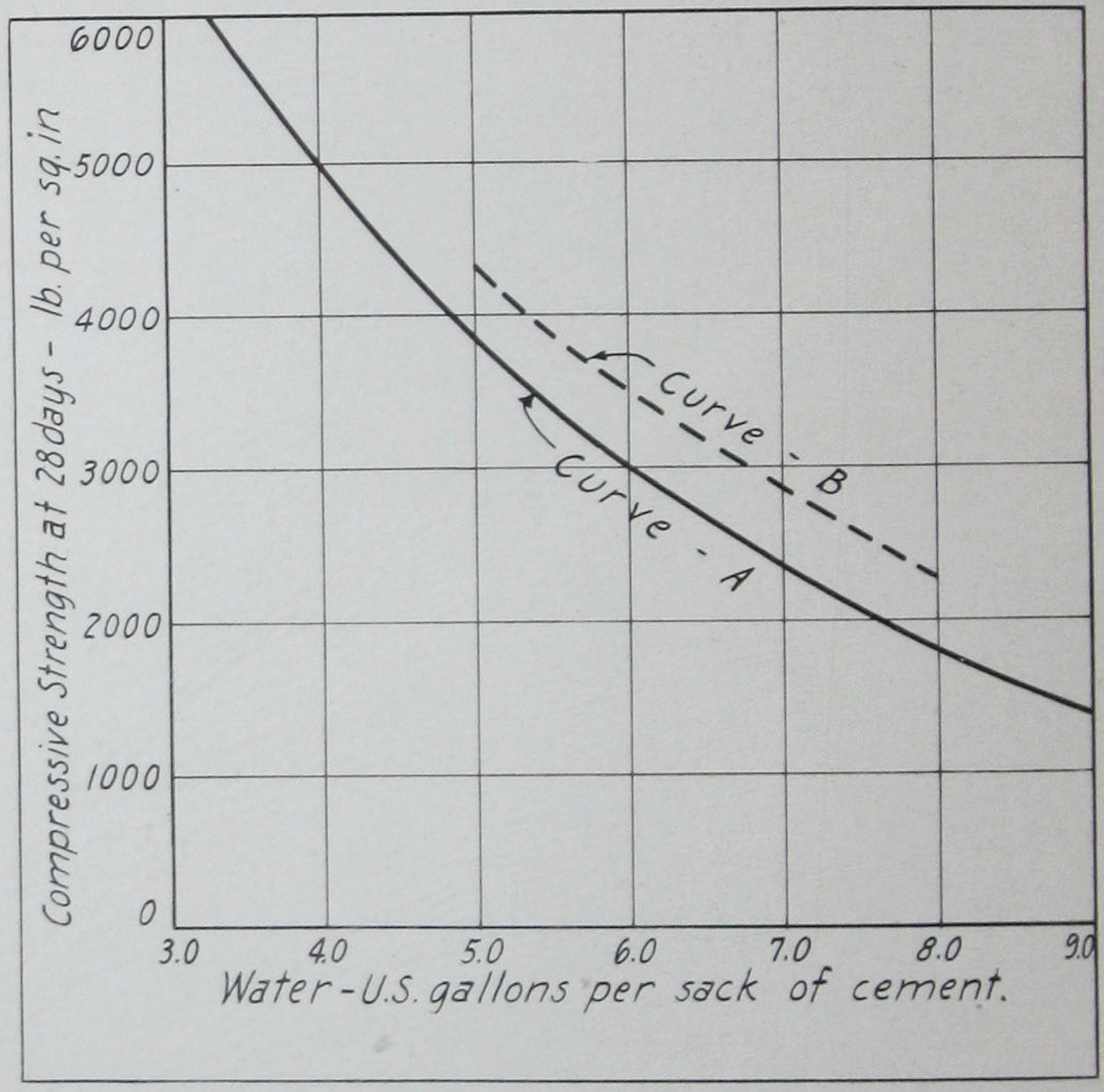
Wider choice of aggregates is made possible by the use of water-cement ratio specifications. By proper adjustments of the mixture, aggregates of widely varying characteristics may be employed under competent direction to secure the desired strength and quality of concrete.

The amount and proportion of aggregates may be adjusted to secure the desired workability.

The bulking effect of moisture in sand may be taken into account.

Improvements in workability and plasticity of concrete are thus made possible.

Better workability and adjustments in the



Effect of quantity of mixing water on the strength of concrete. Curve A is based on average values from nine series of tests made over a period of four years. In the absence of field tests, it may be used for design where the water-cement ratio is carefully controlled by accurate measurement of quantities of water, cement and aggregate with proper correction for water carried by the aggregate. Curve B is a representative job curve obtained from tests of the materials to be used on a specific project. In the "Tentative Building Requirements for Reinforced Concrete" of the American Concrete Institute it is specified that these tests are to be made in advance of the beginning of operations, using the materials proposed and consistencies suitable for the work. The tests are to be made in accordance with the standards of the American Society for Testing Materials and over a range of values including all of the strengths called for on the plans. It is also required that the tests include at least four different water-cement ratios and at least four specimens for each water-cement ratio. The ratio selected should be that corresponding to a point on the curve representing a strength of concrete 15 per cent higher than the minimum ultimate strength called for on the plans.

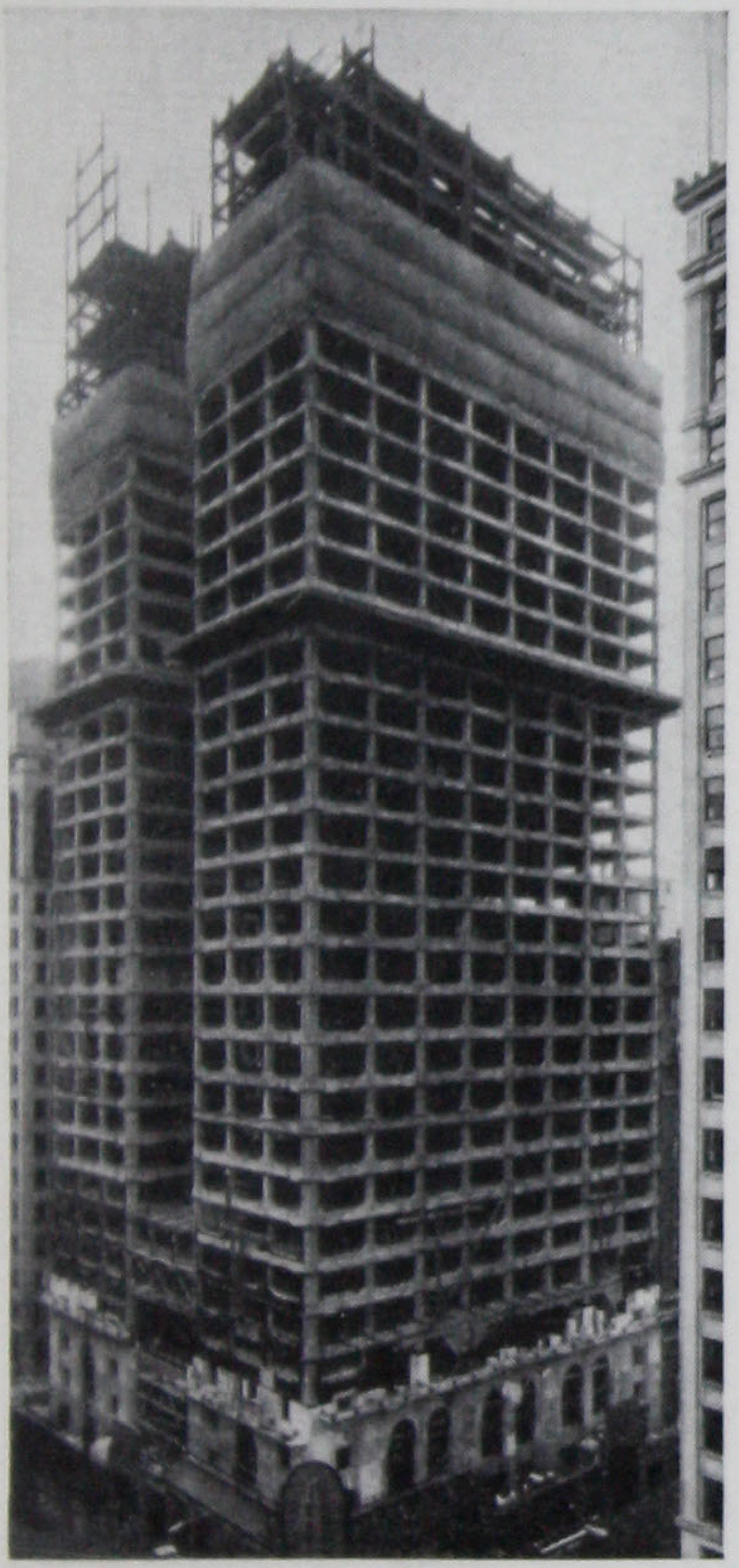
mixture for changes in character of materials give more uniform concrete.

A minimum amount of puddling and spading is required where proper workability and uniform batches are secured.

Labor in placing and in finishing of the concrete is generally reduced.

Improvements are being made in contractors' equipment, resulting in greater uniformity in equipment for a variety of construction purposes.

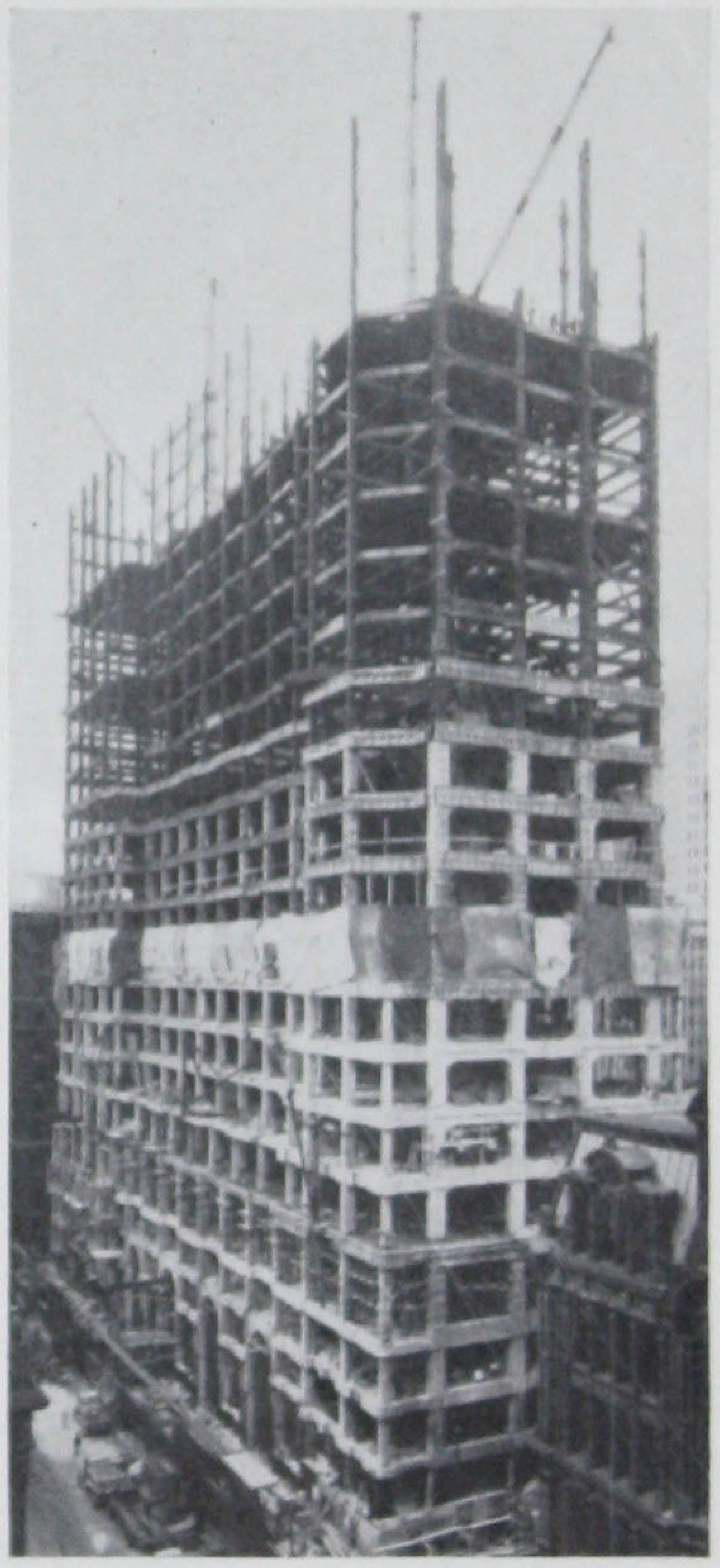
The contractor is given opportunity to use his experience and knowledge of concrete proportioning so he can build economical struc-

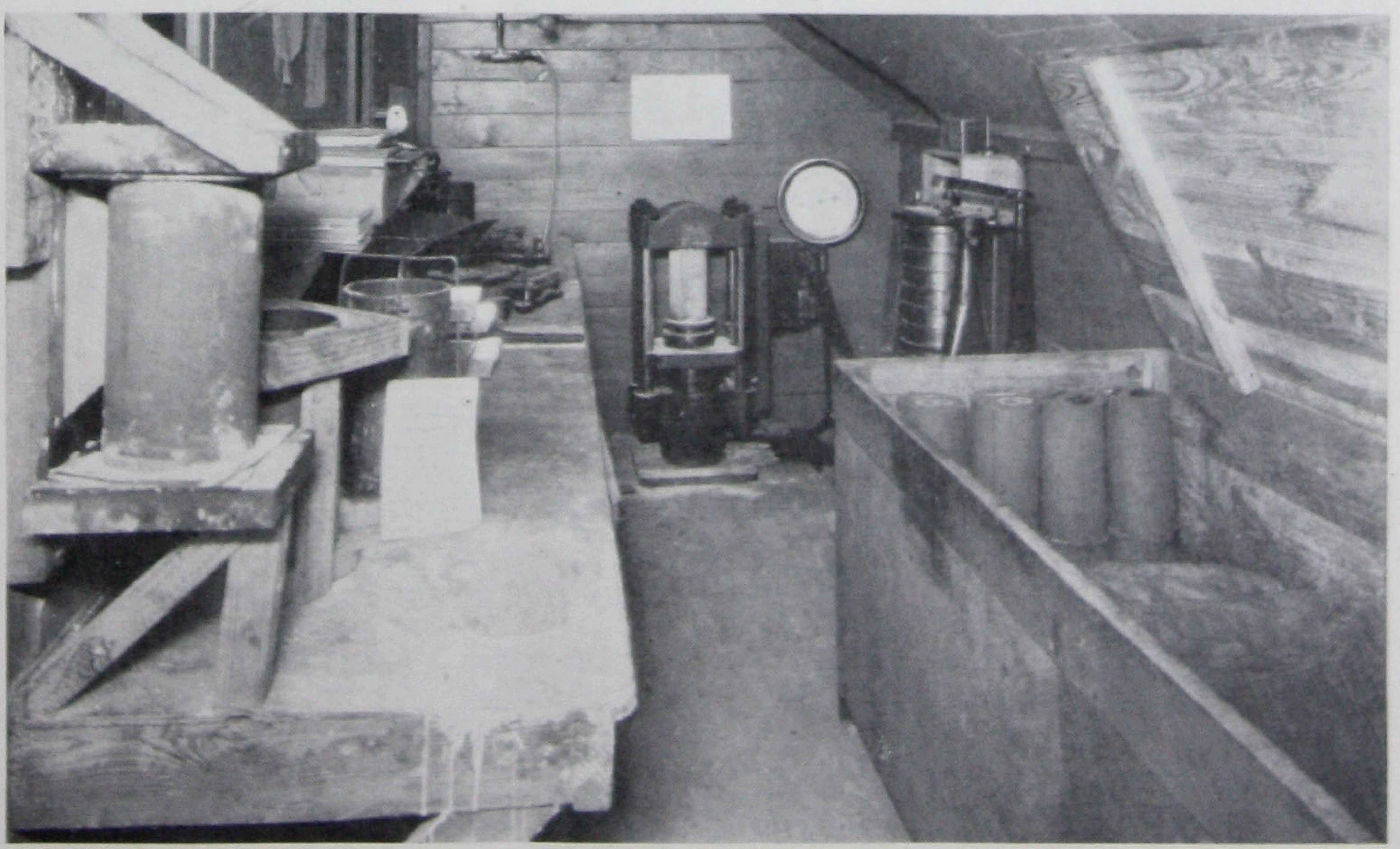


Two of the most recent additions to the business center of Detroit are the Greater Penobscot Building and the Union Trust Building. The Greater Penobscot Building is 47 stories in height, 565 feet above sidewalk level and has caissons 135 feet deep. A field laboratory was installed with equipment for testing the aggregates and the concrete. Close control of the aggregates was maintained by making sieve analyses at frequent intervals. The sand was measured by inundation and the water was accurately controlled. The results proved so satisfactory on the caissons that the method was extended to include all the concrete for the super-structure, assuring the architect and owner of a uniformly high quality concrete at all times. The results of tests on some 1800 cylinders left no doubt as to the quality.

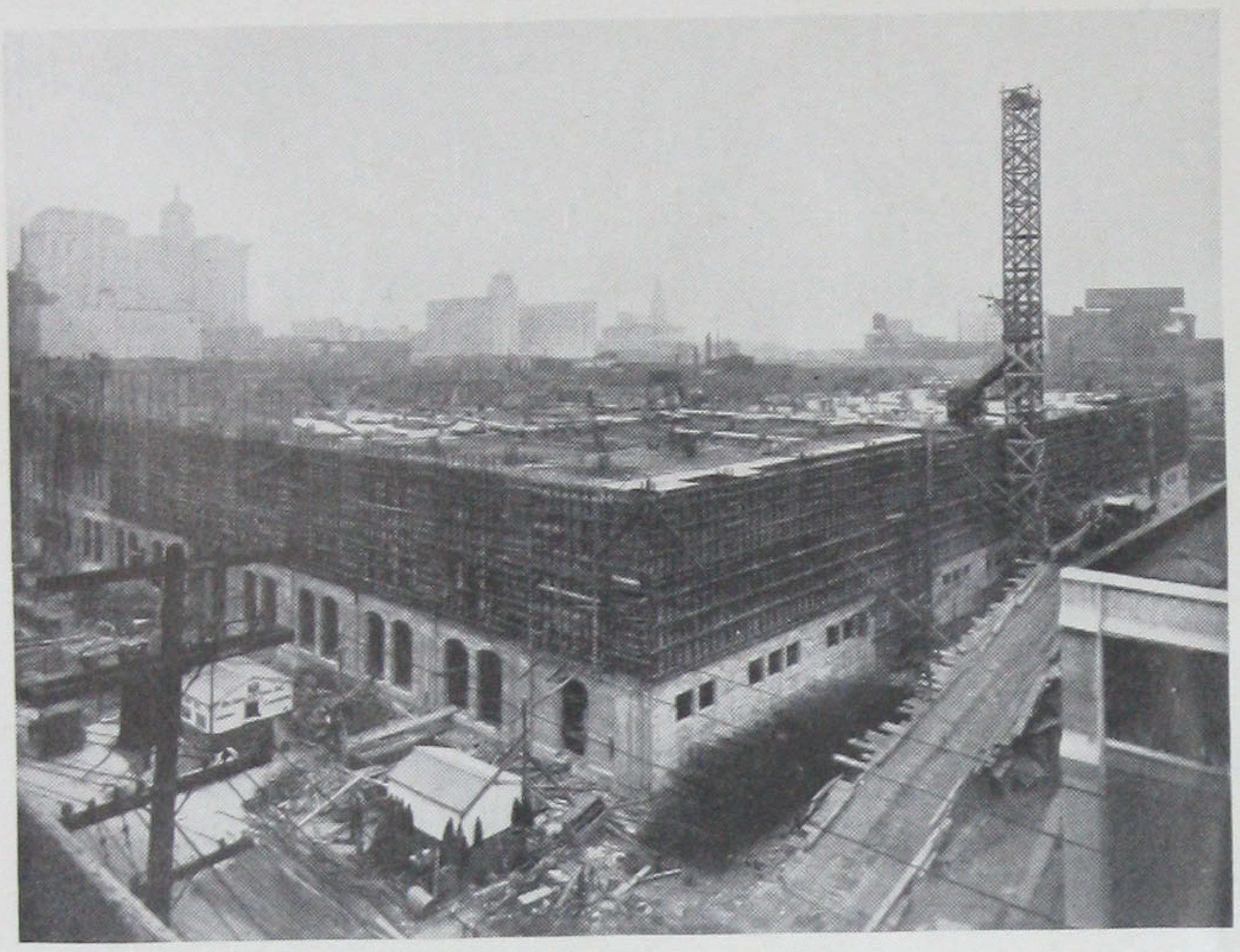
The Union Trust Building is a 40-story project being constructed under the same method. Each day 6 cylinders are made, of which 3 are tested at 7 days and 3 at 28 days. A weekly report showing the results of these tests is furnished the architect and owner, giving them a complete record of the quality of concrete going into the structure.

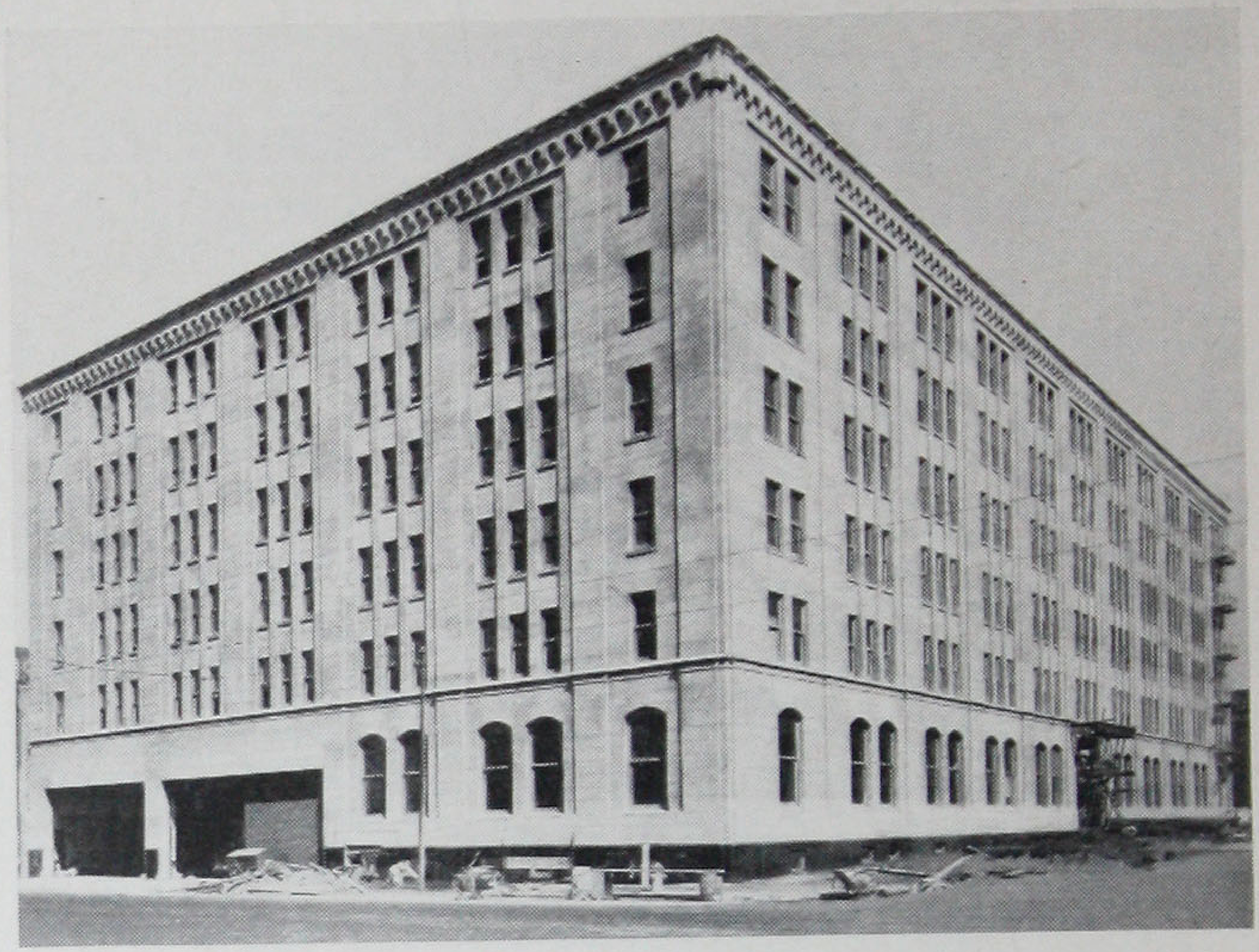
Smith, Hinchman and Grylls of Detroit are the architects for both these projects. Walbridge-Aldinger Co. were general contractors for the foundations and Albert A. Albrecht Co. general contractors for the super-structure of the Greater Penobscot Building. The Union Trust Building is being constructed by W. E. Wood Company.



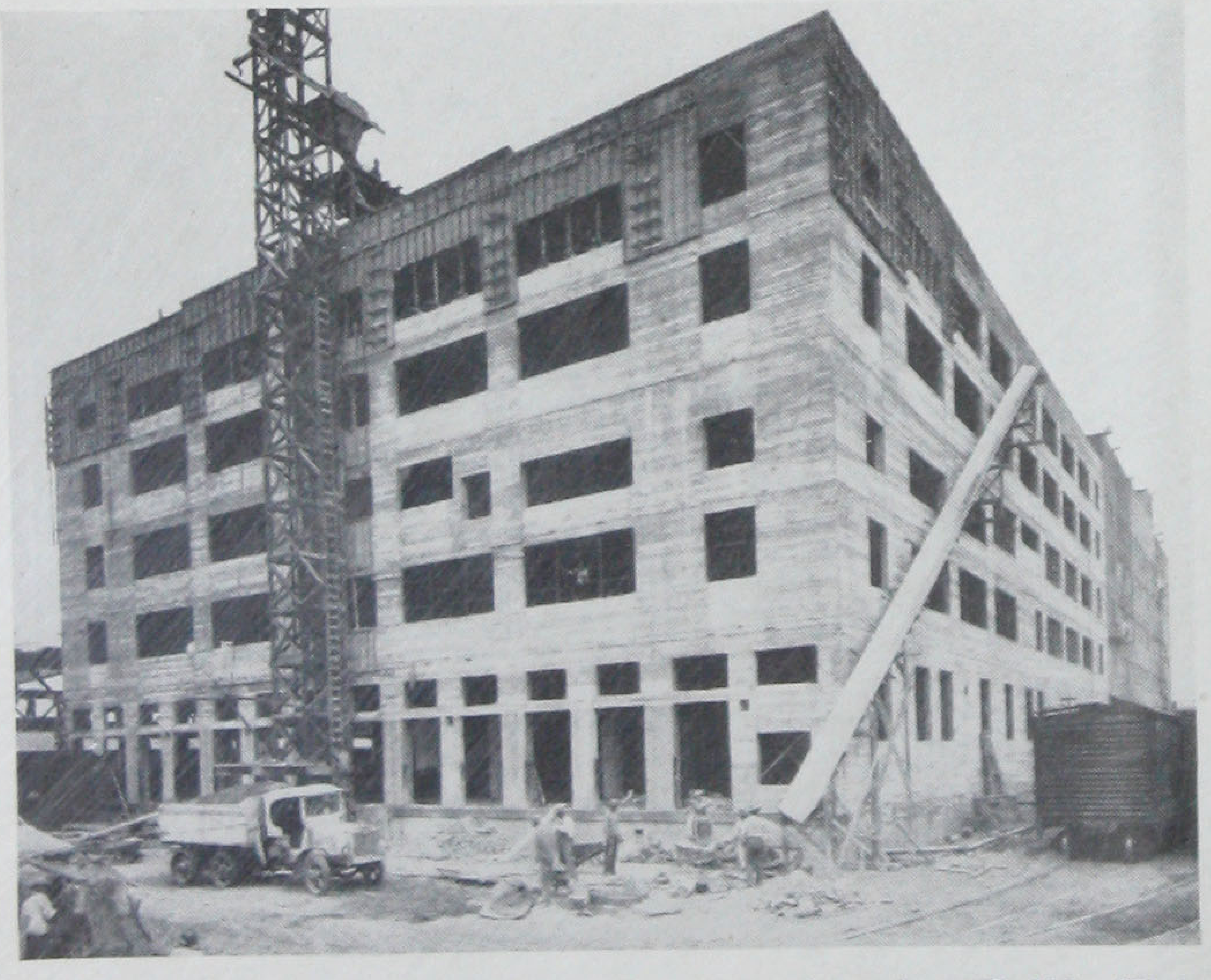


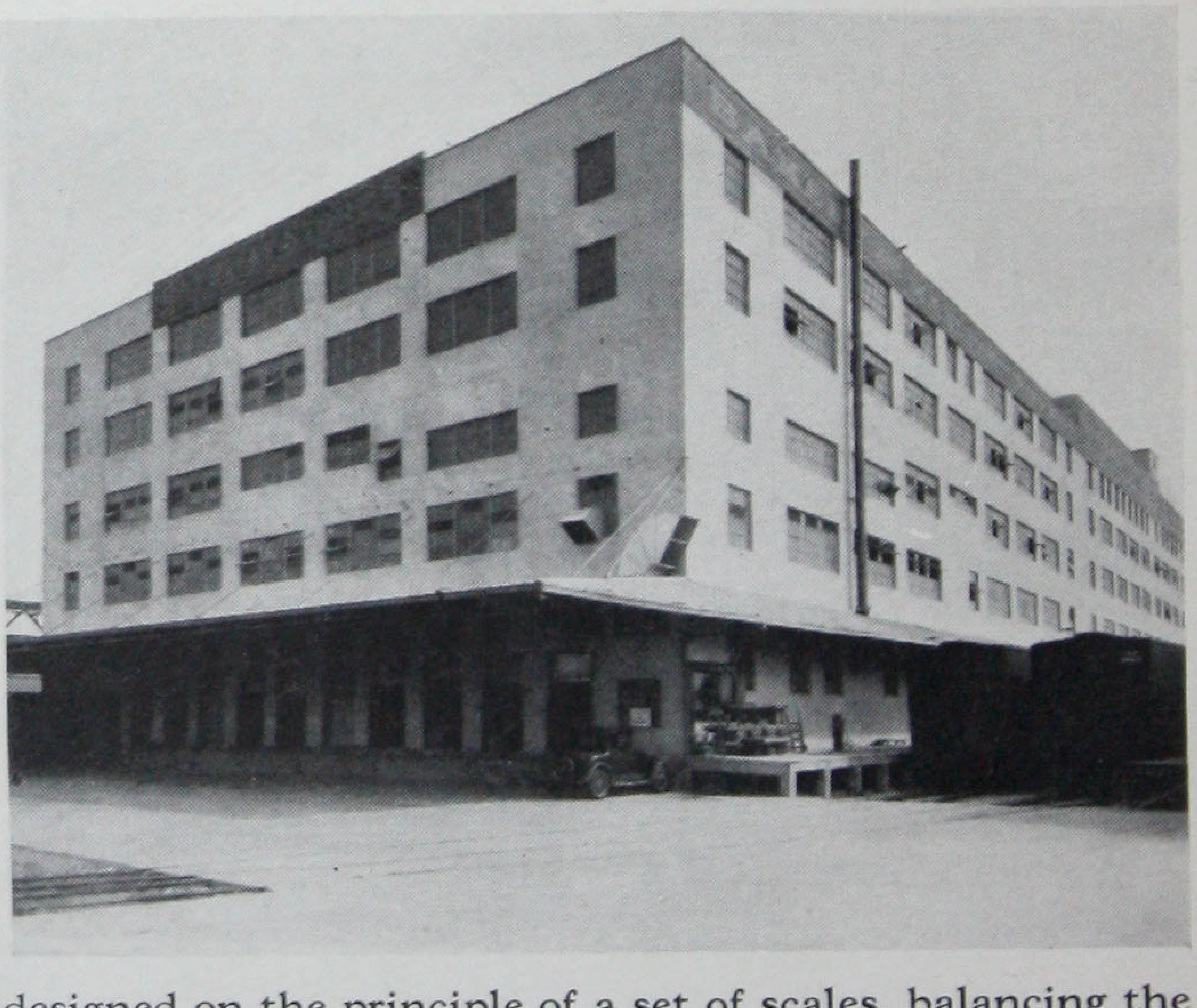
Field laboratory used on typical building project in Detroit. On a job of this size considerable equipment is warranted. The apparatus on the left is for capping cylinders. In the center is shown hydraulic testing machine and vibrating apparatus for making sieve analyses. Storage of test specimens is shown on the right.





Butler Brothers Building, San Francisco, Calif. This is a monolithic concrete building having reinforced concrete frame, floors and exterior walls requiring over 17,000 cu. yd. of concrete. The exterior finish is portland cement stucco. Specifications called for concrete to be mixed with 7½ gallons of water to the sack of cement. Mixes were proportioned by trial and the cement and water were measured by a concrete strength regulator. Bliss & Fairweather, Architects; T. Ronneberg, Structural Engineer; MacDonald & Kahn, Contractors.





Safeway Stores, Inc., Warehouse, Los Angeles, Calif. This is a monolithic concrete building with reinforced concrete frame floors and exterior walls. When the architect was commissioned to prepare plans and specifications for this building, he was instructed to design the structure as economically as possible, but at the same time capable of resisting an earthquake of considerable intensity. It was realized that intelligent and careful design and placing of reinforcement are not effective if the concrete is not prepared with equal care and intelligence. It was therefore decided to control the concrete by application of the water-cement ratio principle.

Trial batches were made using definite quantities of water and cement until the desired plasticity and texture of concrete was reached. A water-cement ratio of one, or 7½ gal. of water per sack of cement, was used. All of the test specimens gave higher strengths than the minimum required. A strength regulator was used, which is an apparatus designed on the principle of a set of scales, balancing the cement against the water. An adjustable weight is used to compensate for the moisture in the aggregate. While the same strength was required in both the walls and the structural frame, it was found that by adjusting the proportions of materials the casting of the walls could be done much more readily. Two different mixes were therefore used. The time required to cast a section of wall was thus greatly reduced. The problem of the exact consistency to use for different parts of a structure is one that must be studied for each case, balancing the cost of materials against the cost of placing. This is one of the many advantages of the water-cement ratio specification as it leads to the best economy without sacrificing quality. William Mellema of Los Angeles was Architect and Consulting Engineer in charge of construction, while George H. Wray was in charge of concrete control for the Steelform Contracting Company, Contractors, of Los Angeles.

tures of excellent and uniform quality, adding to his reputation and lasting credit.

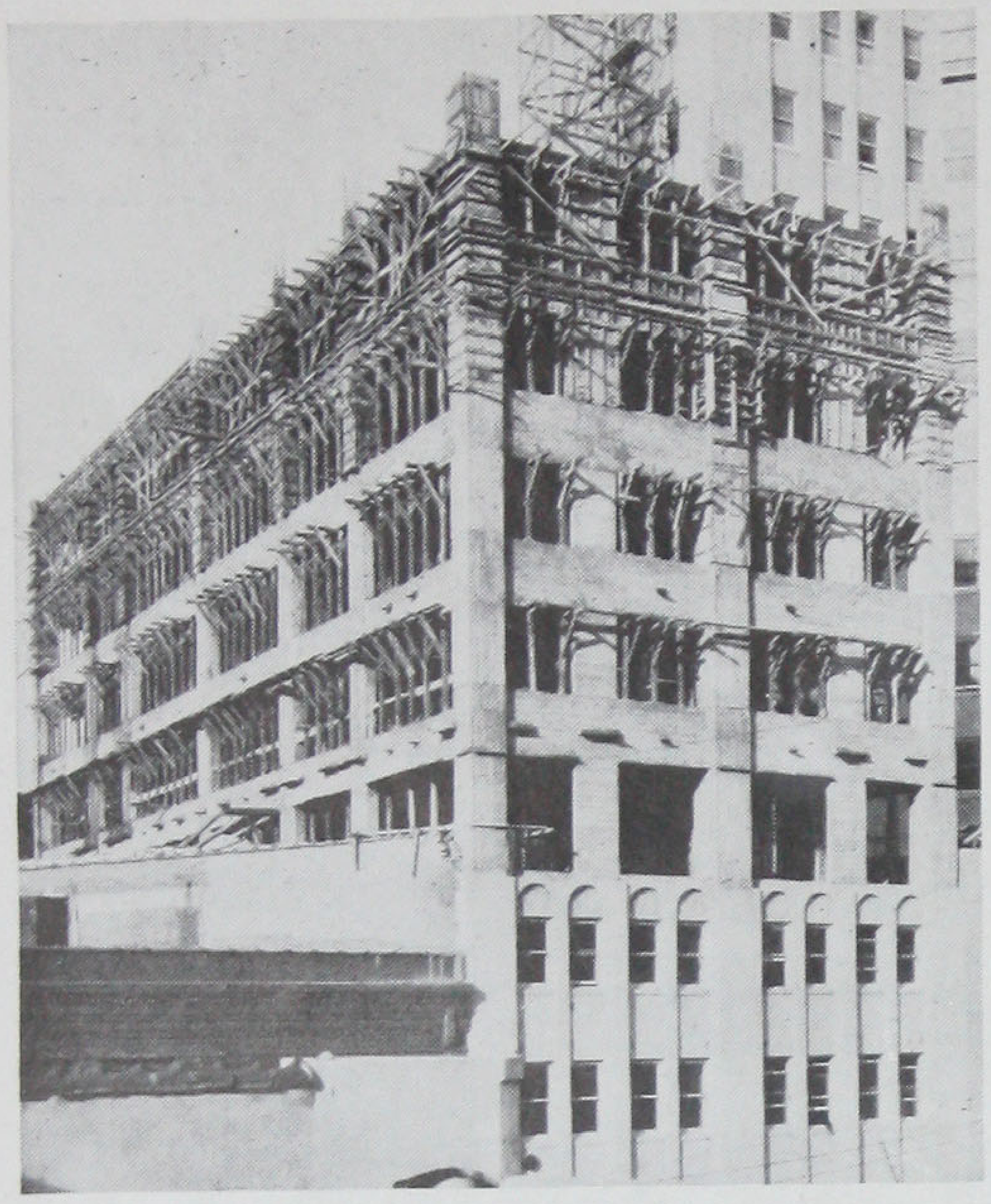
Advantages to Owner, Architect and Engineer

Architects and engineers have constantly objected to the use of overwet mixes as the segregation, laitance, and subsequent porosity which resulted were so apparent. An advantage of specified water-cement ratio is that the interests of the owner and contractor become identical. The contractor finds it to his advantage to use the largest amount of aggregate consistent with workability, thus insuring to the owner the densest and most economical concrete possible for the given strength.

The source of friction between the contractor and the engineer is eliminated. When a very plastic mix is desired it is not obtained at the expense of strength by the addition of water, but by changing the proportion of aggregates to cement or the proportion of coarse to fine aggregates. The conflicting desires of the contractor always to have plastic, workable mixes because they require less labor to place, and yet to keep the cement factor low by the use of the largest possible amount of aggregates, will result in mixes that are suitable for the work.

Large factors of safety to make allowance for slipshod methods of construction are uneconomical and are not justified in the light of present day knowledge. Control of the factors which govern the quality will allow using the material more economically and at the same time eliminate the possibility of weak spots that might otherwise occur. In many structures a consideration of the quality from the standpoint of durability is even more important than the strength. This is especially true of structures designed to withstand hydrostatic pressures and structures exposed to severe conditions of weathering. Such durability can only be assured by proper control of all the factors which affect the quality. Control of the water-cement ratio in concrete is necessary

The new warehouse building erected for the Philadelphia Wholesale Drug Company at Philadelphia is a demonstration of the fact that better quality and economy often go hand in hand when the principles underlying the proper use of a material are thoroughly understood. The concrete was specified to contain a maximum of 7½ gal. of water per sack of cement. All sand was measured by inundation to make automatic allowance for the bulking caused by moisture. The water added to the mix was carefully regulated. Test cylinders of the concrete were made and indicated a higher compressive strength than required. This was accomplished with a cement factor which, under the older arbitrary mix method of proportioning, would be depended upon to produce concrete with compressive strength about 1000 lb. per sq. in. below that obtained. Thus no additional expense is incurred in producing a product of known and uniform quality and often a real saving can be shown. Rankin & Kellogg, Architects; Harris & Richards, Engineers; Turner Construction Co., Contractors.



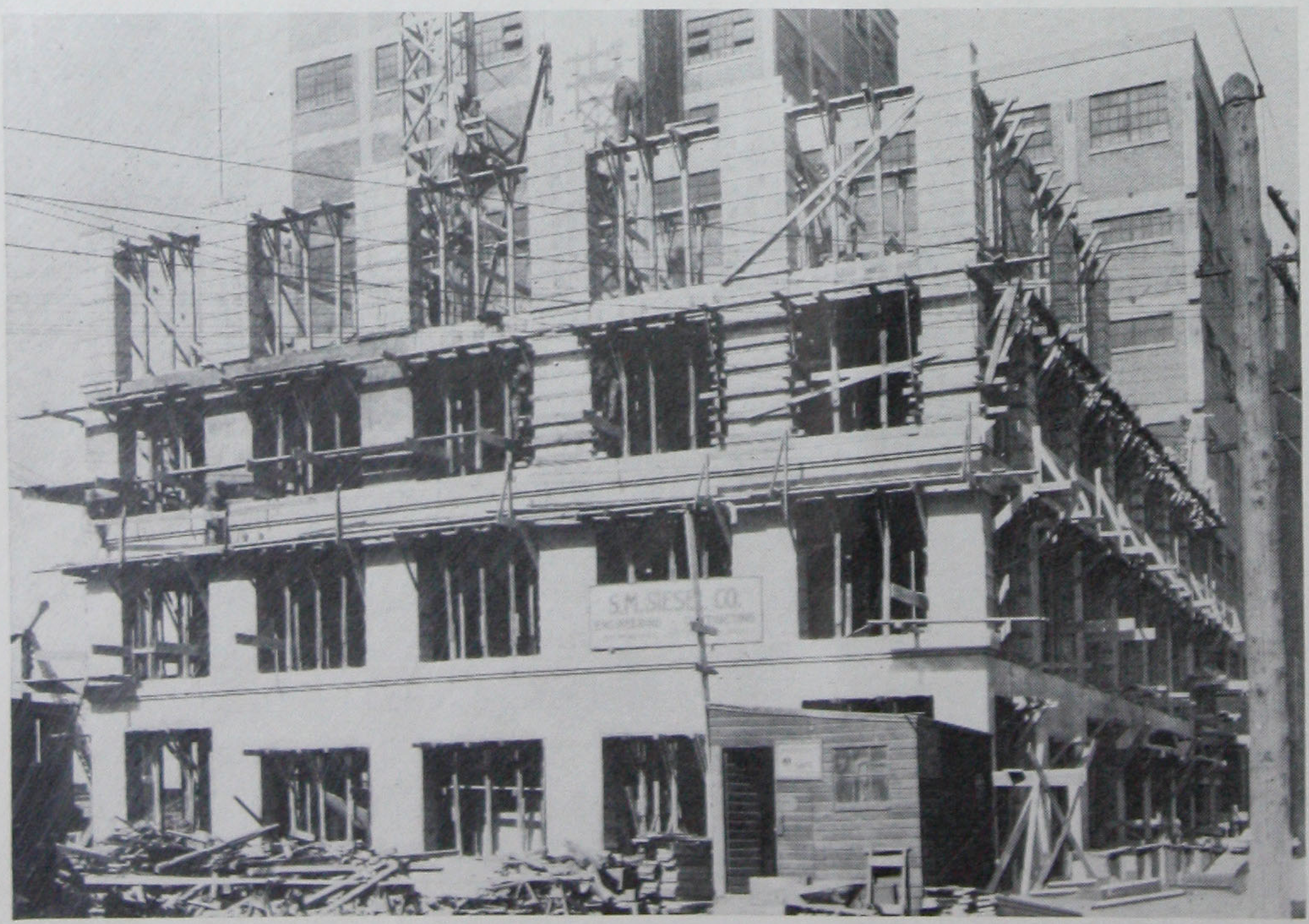
Medical Arts Building Annex, Dallas, Texas. The annex consists of one wing of 14 stories added on top of a four-story section, making a total height of 18 stories or 229 feet. Reinforced concrete with brick veneer exterior. Three classes of concrete were specified, using 7½, 6¾ and 6 gal. of water per sack of cement. Specimens were made at frequent intervals. The results were uniformly higher than the minimum requirements. Herbert M. Greene & Company, Architects; R. O. Jameson, Structural Engineer; McKenzie Construction Co., Contractors.

to the production of a uniform product of known quality. That this may be done at no additional cost is one of the great advantages to all concerned.

Development of the Job Curve

Identical conditions do not, of course, prevail on all construction work. The materials and the method of their manipulation, time of mixing, temperature and amount of moisture present during curing, all influence the strength and quality of concrete. With each set of conditions, however, there is a definite and easily determined relation between the strength of the concrete and the water-cement ratio.

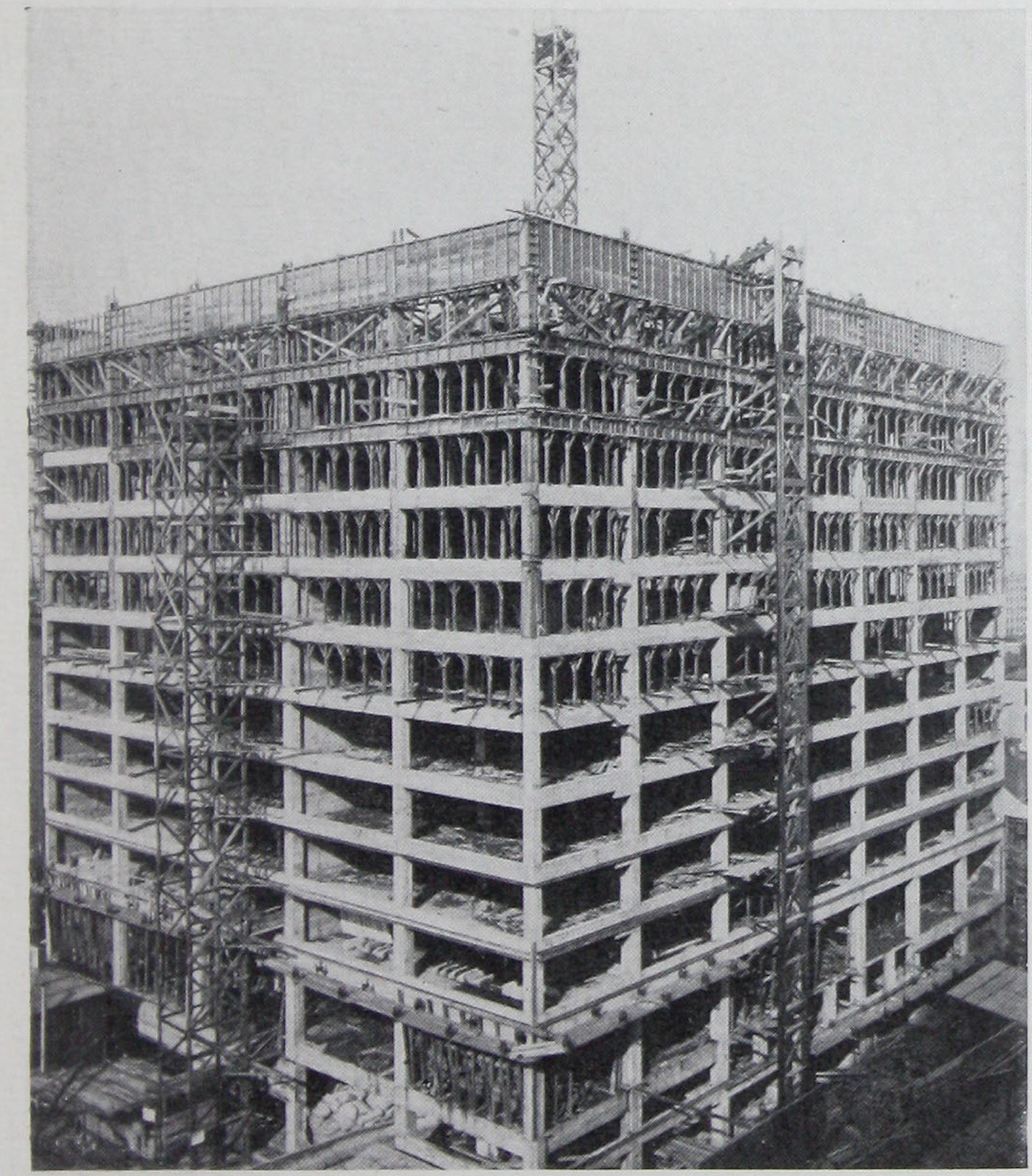
While tables and curves have been developed to represent average conditions of manipulation and average materials, a more recent de-



Teweles Seed Co. Warehouse, Milwaukee, Wis. This building was designed for heavy floor loads and with a large surface area of concrete exposed to severe weather conditions. The specifications called for definite amounts of mixing water in the concrete. The mix was varied for different conditions of placement. In certain parts a slump of only one inch was used and in places where the sections were smaller and had more reinforcement the slump ranged up to 7 inches. The differences in slump were obtained by varying the amount and proportions of aggregate without changing the water-cement ratios. The Fraser Company, Engineers; S. M. Siesel Company, Contractors.

velopment has been the job curve. A typical job curve is represented by Curve B on page 4. Preliminary tests are made with the materials to be used on the job, with several different water-cement ratios and methods of manipulation representative of those to be used on the job.

From these values a curve is constructed to represent actual working conditions on that particular project. The preliminary tests should be sufficient in number to assure a true representation of these conditions. As the work proceeds, additional values are obtained from time to time to check the accuracy of the job curve. Such a curve is especially of value on projects involving large quantities of concrete as the utmost in economy can then be realized.

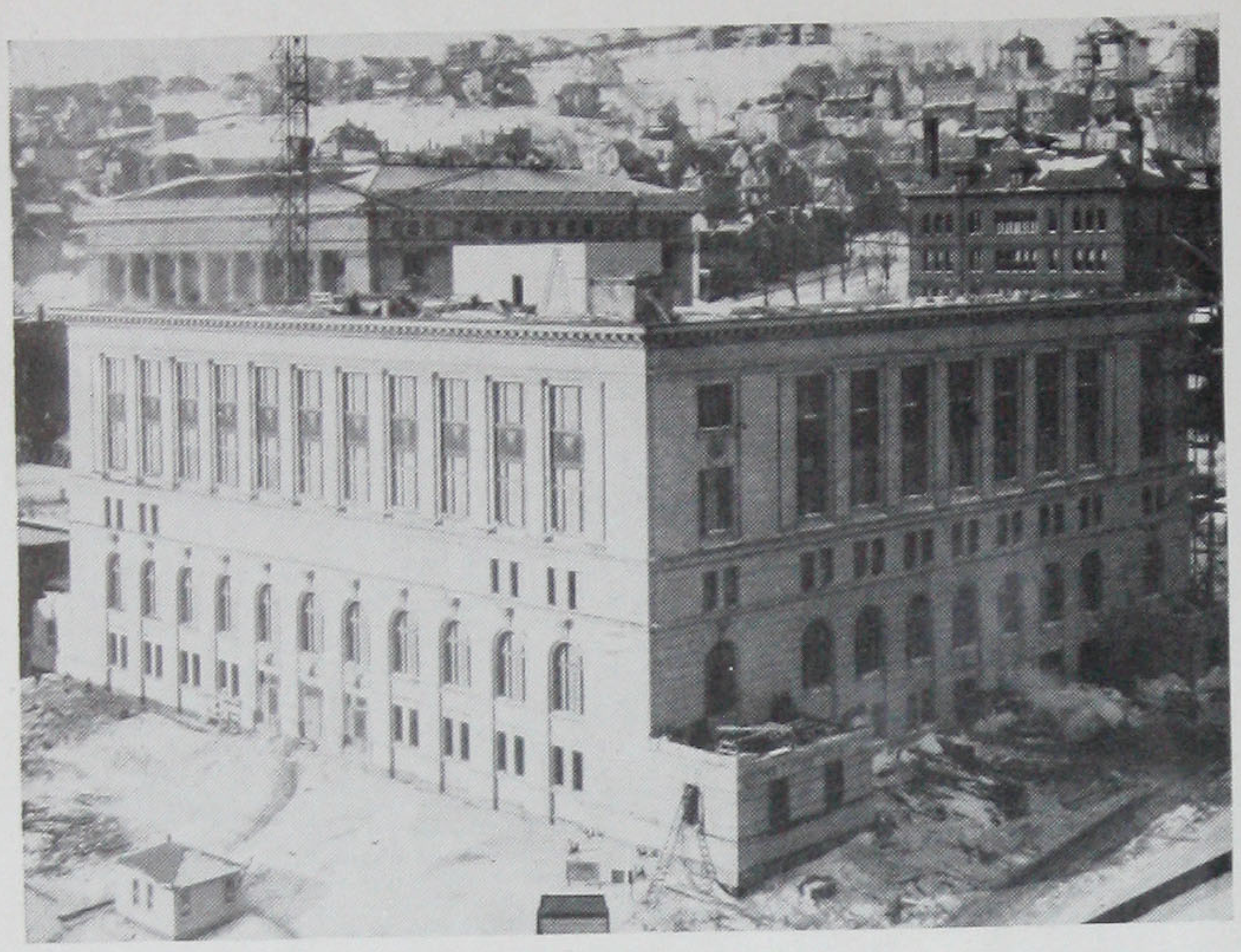


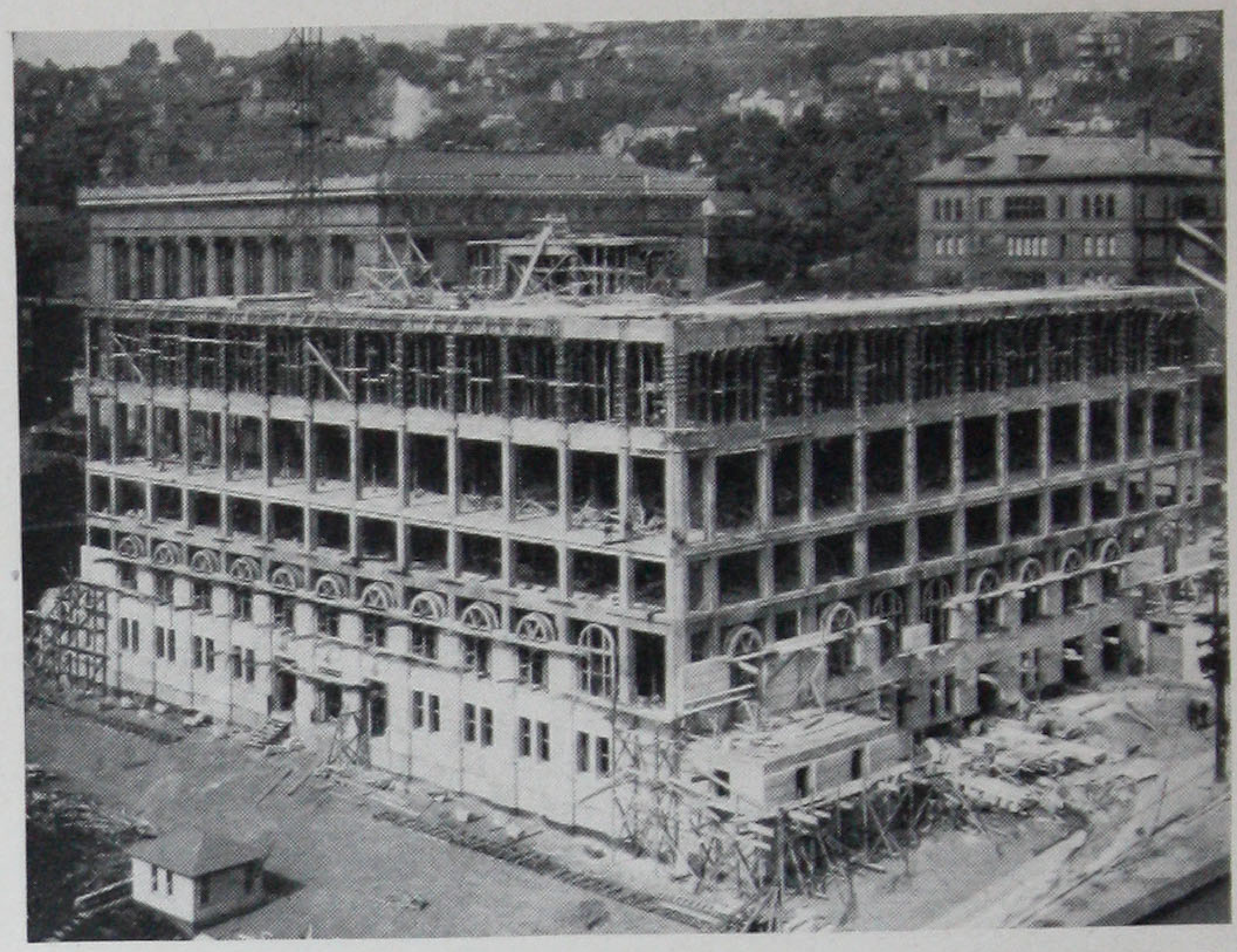
Building Code Provisions

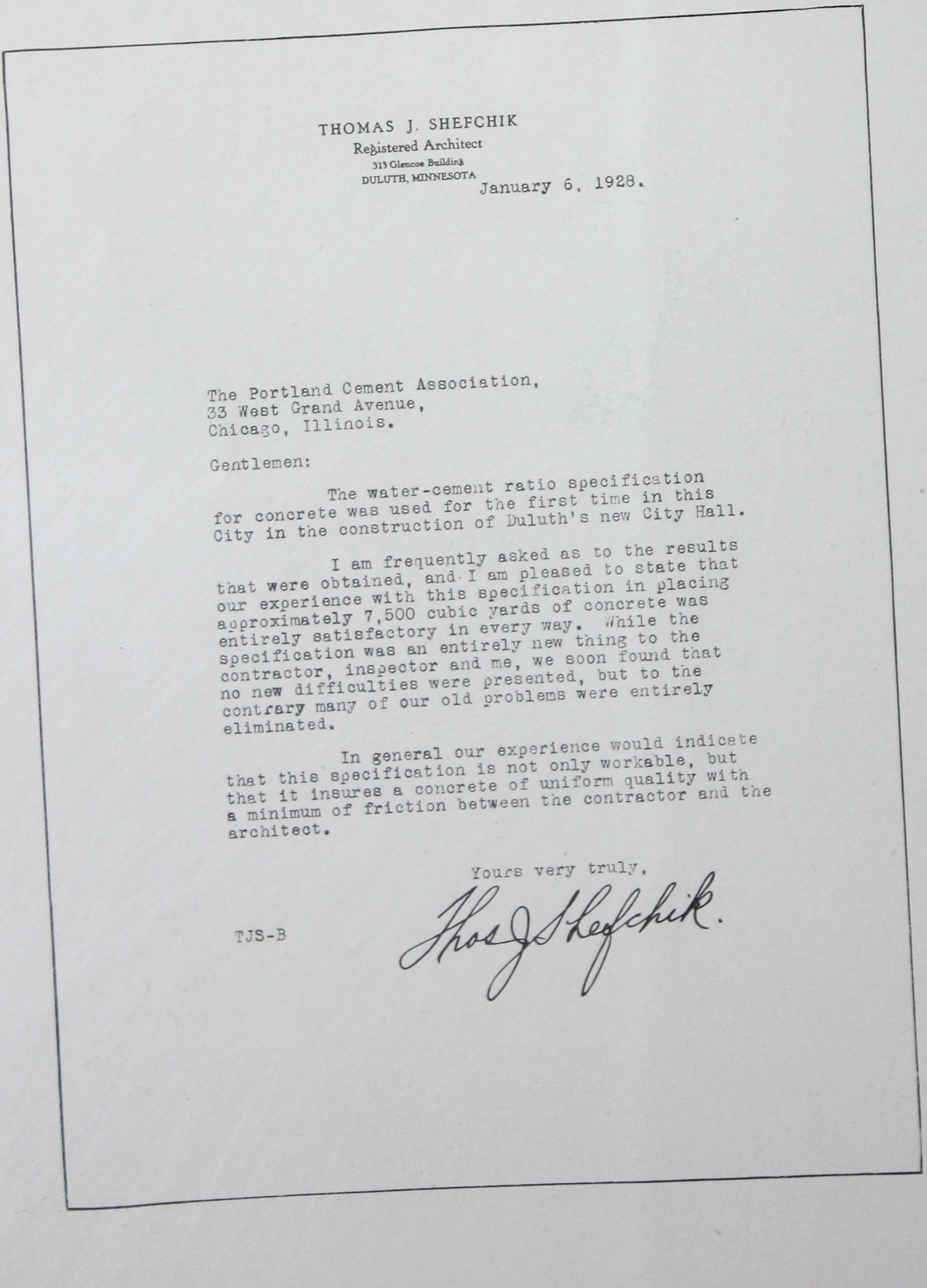
When the Building Code Committee of the Department of Commerce, appointed by Secretary Herbert Hoover to draft a standard code for working stresses in building materials, was convened, it was immediately recognized that a better method of specifying concrete than the arbitrary mix method was desirable. After due consideration, the water-cement ratio specification was adopted.

Hotel Georgia, Vancouver, B. C., Canada. This 12-story building required about 7000 cu. yd. of concrete, all of which was closely controlled. Columns of lower 7 floors were designed for concrete with compressive strength of 3200 lb. per sq. in. and all other concrete for 2200 lb. per sq. in. No special equipment was used for measuring materials. Sieve analyses of aggregates made daily. Results of cylinder tests gave extremely uniform and satisfactory results. R. T. Garrow, Architect; John Graham, Consulting Architect; Dredging Contractors, Ltd., Contractors.

Similar provisions have been incorporated in the "Recommended Uniform Building Code for Pacific Coast Cities" of the Pacific Coast Building Officials Conference. This code is being used by nineteen cities on the Pacific Coast and others will soon follow their example. The building codes of such cities as Des Moines, Ia., Kansas City, Kans., Shreveport, La., Ft. Worth and Dallas, Texas, Dayton, Ohio, and Indianapolis, Ind., have been revised to incorporate the water-cement ratio method.







THOMAS J. SHEFCHIK
Registered Architect
313 Glencoe Building
DULUTH, MINNESOTA

January 6, 1928.

The Portland Cement Association,
33 West Grand Avenue,
Chicago, Illinois.

Gentlemen:

The water-cement ratio specification for concrete was used for the first time in this City in the construction of Duluth's new City Hall.

I am frequently asked as to the results that were obtained, and I am pleased to state that our experience with this specification in placing approximately 7,500 cubic yards of concrete was entirely satisfactory in every way. While the specification was an entirely new thing to the contractor, inspector and me, we soon found that no new difficulties were presented, but to the contrary many of our old problems were entirely eliminated.

In general our experience would indicate that this specification is not only workable, but that it insures a concrete of uniform quality with a minimum of friction between the contractor and the architect.

Yours very truly,

Thos J Shefchik.

TJS-B

City Hall, Duluth, Minn. First structure in Duluth to be built under the water-cement ratio specification. The building contains about 7500 cu. yd. of concrete. The water content for the concrete in the columns was limited to 6 gallons and for all other members 7½ gallons per sack of cement. An inundator was used for measuring sand and water. Thomas J. Shefchik, Architect; George H. Lounsberry & Sons, Contractors. Not only is concrete of uniform and predetermined quality easily made under this specification but many of the causes for contention between those who plan and execute the work are eliminated as attested to by Mr. Shefchik's letter reproduced here.

Pittsburgh, Washington, New Orleans, Detroit and other cities permit full utilization of the strength of concrete as determined by test. It is only a question of time when the majority of city building codes will have incorporated this method and will give designers and owners of buildings and other structures the benefit of whatever superior qualities may be possessed by materials for concrete in the local market.

Standard Practice of Large Users

Many of the large industrial concerns are continually engaged in investigating the possibilities of new materials and improved methods of making and using materials to their greatest advantage. Some of the large users of concrete have employed well-qualified engineers to supervise the control of concrete and from their experiences on many projects have found that modern methods of concrete control are well worth while. The splendid results obtained have almost invariably led these firms to adopt such methods as standard practice on all concrete work.

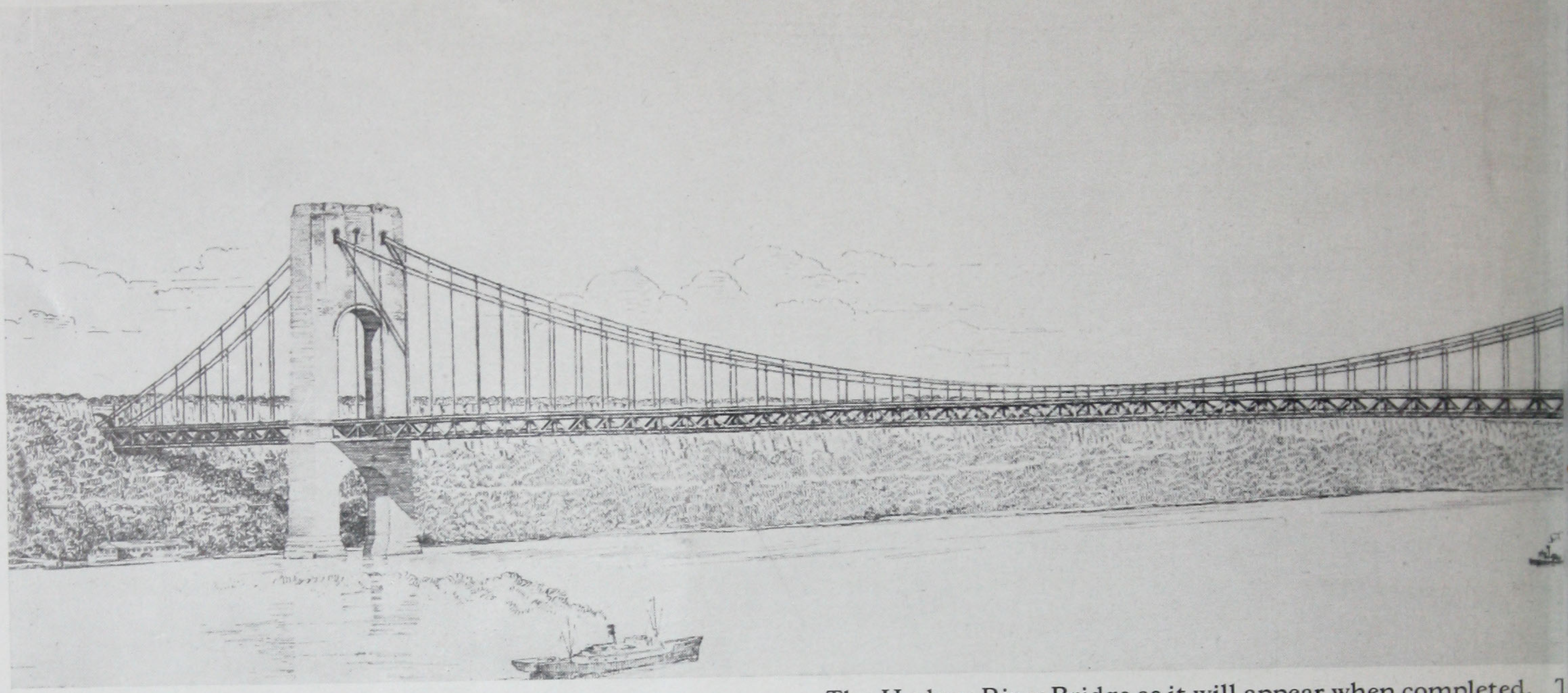
Marberc Hotel, New Orleans, La. Reinforced concrete structural frame and floors. This view, taken November 1, 1927, shows five stories of the frame completed and form work being set for sixth floor. Concrete for the floors was designed for 2000 lb. and for columns 2500 lb. per sq. in. An inundator was used to measure sand and water. Emile Weil, Inc., Architect; R. P. Farnsworth & Co., Contractor.

Marberc Hotel Building on December 1, 1927, exactly one month later. In this month, 7 stories were added to the frame and exterior brickwork placed on 5 stories. To keep up such a schedule and preclude the possibility of accidents, it is essential that the concrete be of good quality, properly controlled.

Among the large users of concrete are public utilities, especially where dams and power projects are involved. These structures involve great volumes of concrete that are often subjected to very severe conditions. Nearly all such structures are now being built under adequate supervision, using the newer methods of control. This is being done without adding to the cost and often showing an actual saving.

Quality Control on Concrete Highways

One of the largest uses of concrete is in the construction of concrete road and street pavements and the increasing demands of the

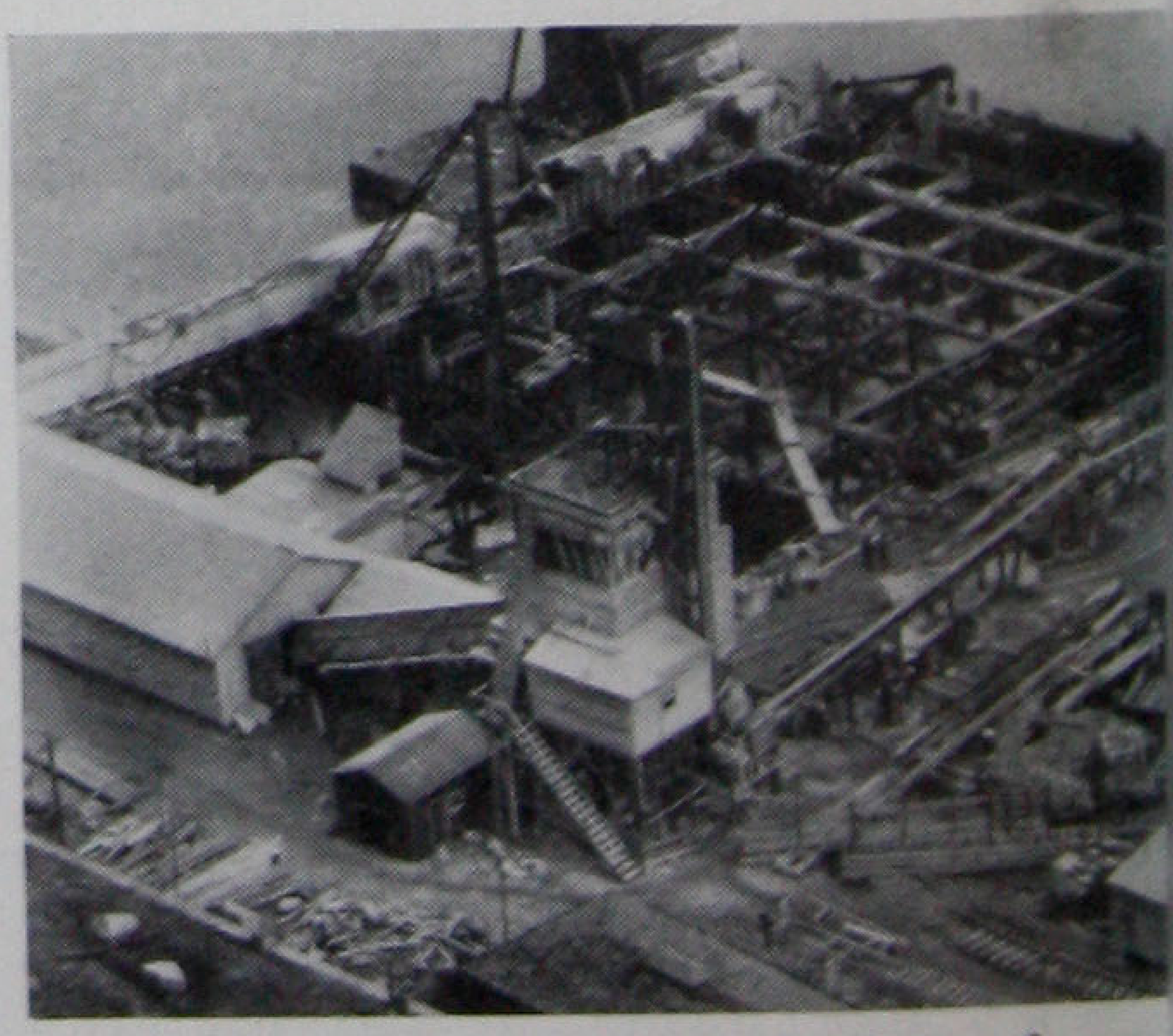


The Hudson River Bridge as it will appear when completed.
built previously. The piers

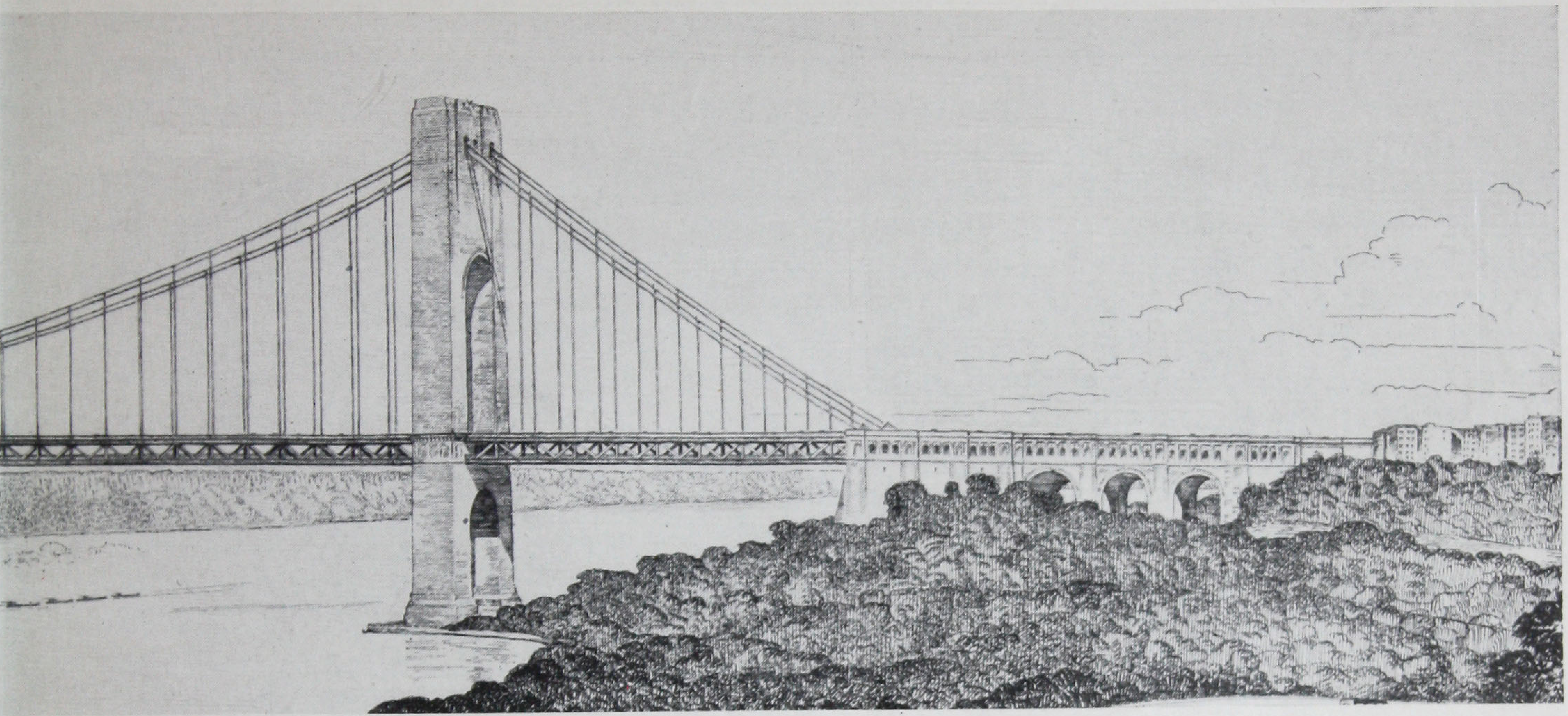
Control of Con
Greatest Susp

Elizabeth-Howland Hook Bridge.

IN a structure which is to stand indefinitely, every precaution is necessary to provide materials that will endure. The Port of New York Authority therefore adopted the water-cement ratio specification for the Hudson River Bridge which involves some 465,000 cubic yards of concrete. The same specification had been successfully applied on the Elizabeth-Howland Hook and the Perth Amboy-Tottenville Bridges over the Arthur Kill between Staten Island and New Jersey. On the Hudson River Bridge, preliminary tests were made with the job materials to determine the exact relation between the water-cement ratio and the strength of concrete under job conditions. From these tests the exact amount of water required to produce the desired strength of 2000 pounds per square inch at 28



One of the foundations for a



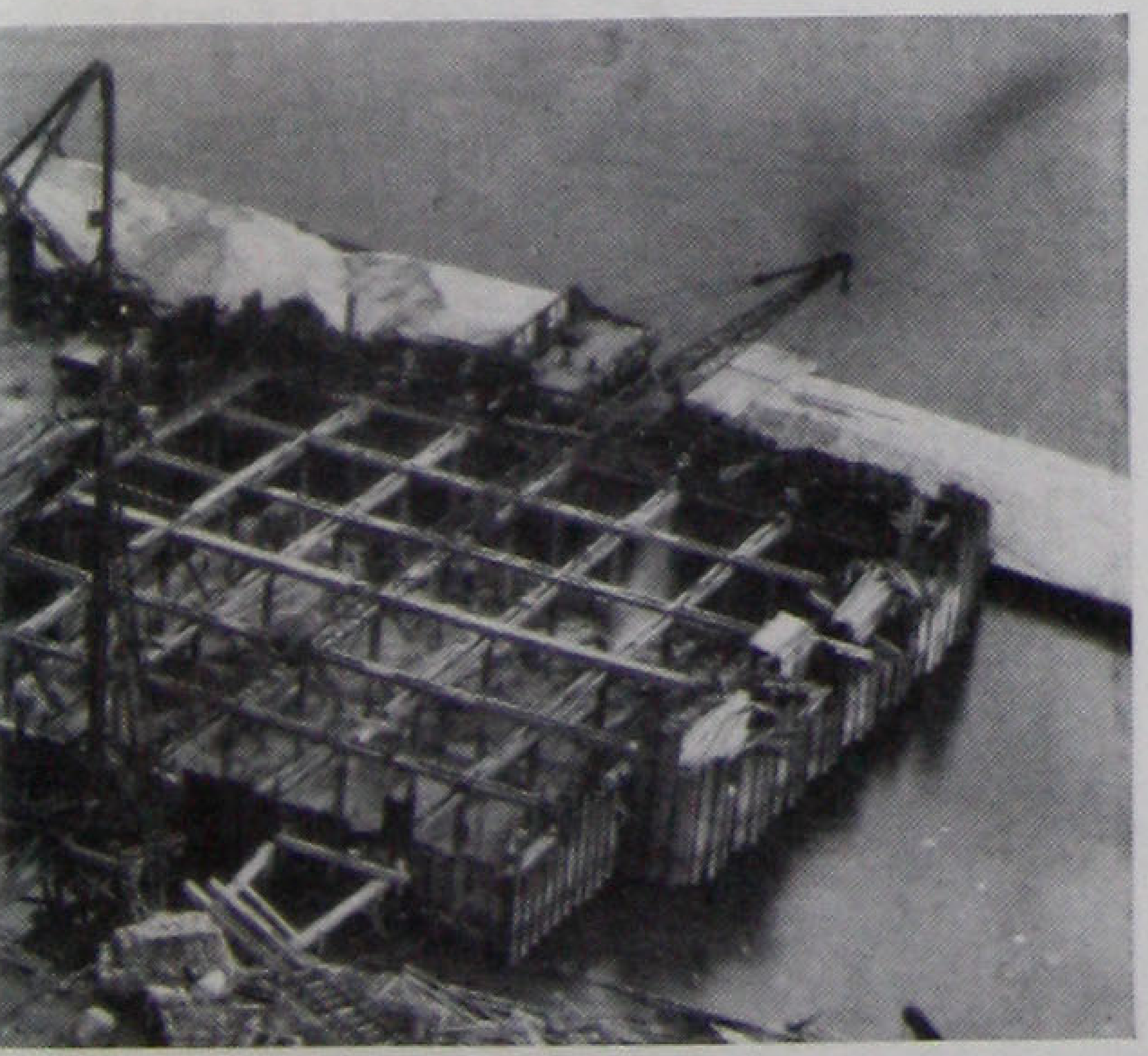
ıspension span of 3500 ft. is exactly twice the longest span
625 ft. above water level.

rete on World's nsion Bridge

Piers of the Perth Amboy-Tottenville Bridge.

days and the most economical mix were determined. All of the ingredients of the concrete are accurately controlled. Weighing batchers are used for measuring the aggregates and the water is measured in a volumetric tank. The contractor for the foundations of the New Jersey tower bases shown in the accompanying views is Silas Mason, Inc., New York City. The towers were designed by Cass Gilbert, Architect, New York City. The contract was executed under the direction of O. H. Ammann, Chief Engineer of Bridges of the Port of New York Authority, Montgomery B. Case, Engineer of Construction, and F. E. Cudworth, Resident Engineer of the Hudson River Bridge.

A. W. Munsell is Engineer in Charge of Tests.

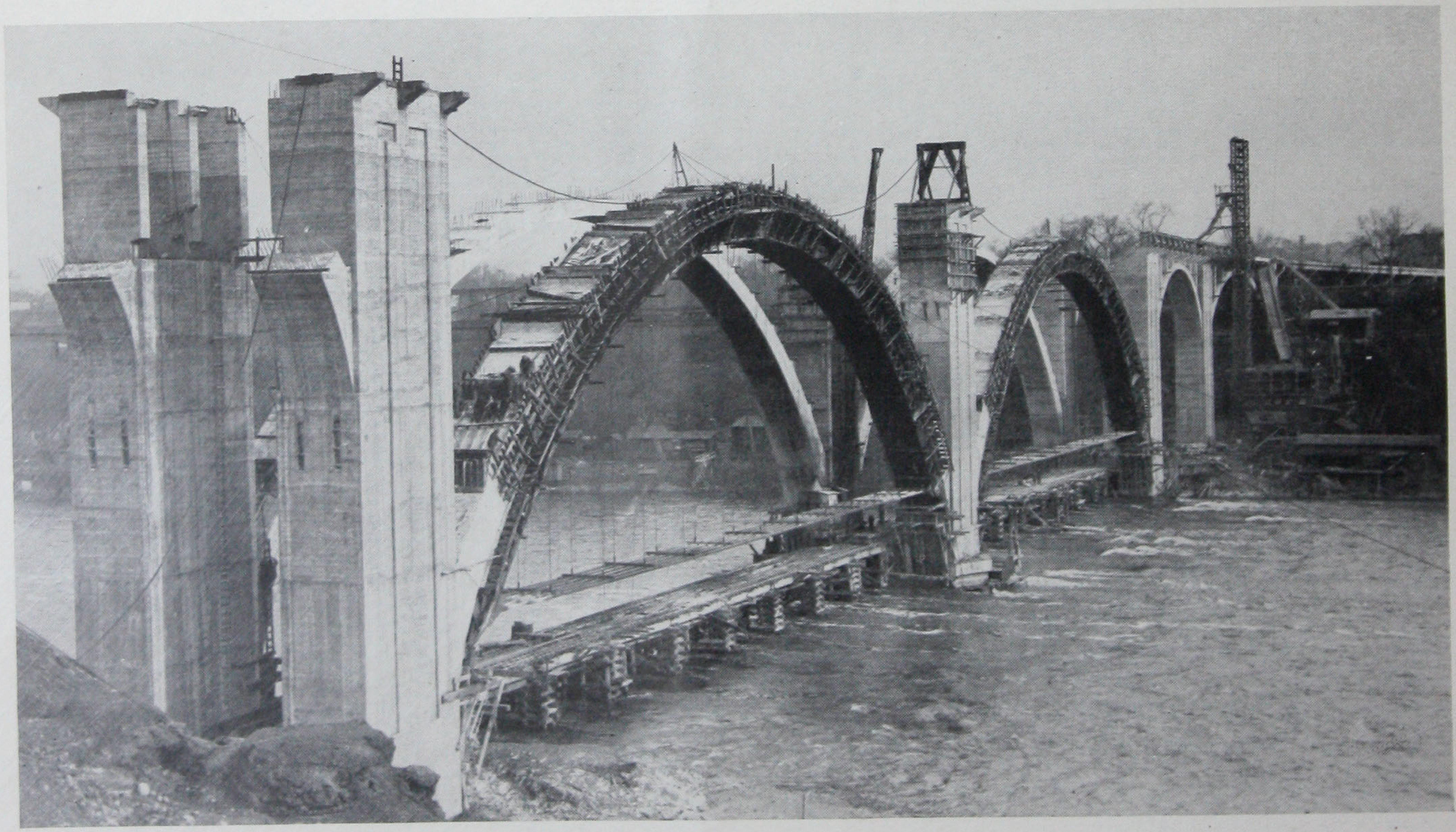


of the Hudson River Bridge.

rapidly growing traffic have meant a larger paving program each year. An immense amount of work has been done to determine the best construction practice. Specifications are rigid and are strictly enforced. They represent the results of years of experience and testing by a large group of especially well qualified engineers. The specifications of the highway departments of 15 states now specify the exact amount of mixing water that may be used and require the accurate measurement of the water. These include California, Colorado, Connecticut, Iowa, Maine, Minnesota, Missouri, Nevada, New Hampshire, New Jersey, New Mexico, Rhode Island, Tennessee, Vermont and Wyoming. The specifications of practically all the other state highway departments control the amount of mixing water by strict requirements as to consistency. Municipalities have followed the example of the state departments and are rapidly adopting similar specifications for their paving work.

Railways Improve Their Methods

In March, 1927, at their annual convention, the American Railway Engineers Association adopted a water-cement ratio specification as standard for all railway concrete construction. This specification was not new or untried on railway work; as a group the railway engineers had had more experience in proportioning concrete by this method than any other group of



Cedar Avenue Bridge, Minneapolis, Minn.

The entire structure is reinforced concrete, requiring some 30,000 cubic yards of concrete. It is being built by day labor under the supervision of the Minneapolis Engineering Department. Much of the concrete was placed during the winter under the low temperatures prevailing in Minneapolis during this season. The excellent quality of the concrete was obtained by controlling the water-cement ratio, designing the mix from studies of the materials and accurately measuring the materials. Sieve analyses of the aggregates were made from time to time and the mixes proportioned on the basis of these analyses. An inundator was used to measure the water and fine aggregate. The coarse aggregate was measured by volumetric batchers.

Considering the great difference in temperature and atmospheric conditions between summer and winter, the results are very uniform. Upon removal of the forms it was found that the concrete presented a uniformly dense surface of even texture, requiring a minimum of patching. F. T. Paul, Senior Assistant Bridge Engineer, is in active charge of construction, N. W. Elsberg is City Engineer, and Krist Oustad is Bridge Engineer.

Brocklebank Apartments, San Francisco, Calif. The structural frame, floors and exterior walls are reinforced concrete. The exterior finish is portland cement stucco. This building was designed especially to withstand earthquake shock and is one of the first to be erected on the Pacific Coast under a water-cement ratio specification. A barrel with an adjustable overflow and in charge of a competent inspector was used to measure the water. Samples of the concrete were taken regularly and tested about 20 per cent higher than the required 2000 lb. per sq. in. Weeks & Day, Architects.

engineers. The railroads had been trying several different forms of concrete control with various degrees of success and their engineers realized the desirability of a simple, yet accurate, method that would produce the desired results. Thus sentiment favoring the water-cement ratio method grew gradually, culminating in its acceptance as a standard.

As a result of the adoption of this specification by the American Railway Engineers Association, additional railroads have used similar specifications on one or more projects and over twenty railroads are using these methods of concrete control as standard. One of the most significant features of this growth is that no road which has given these methods a trial has considered going back to the old methods.

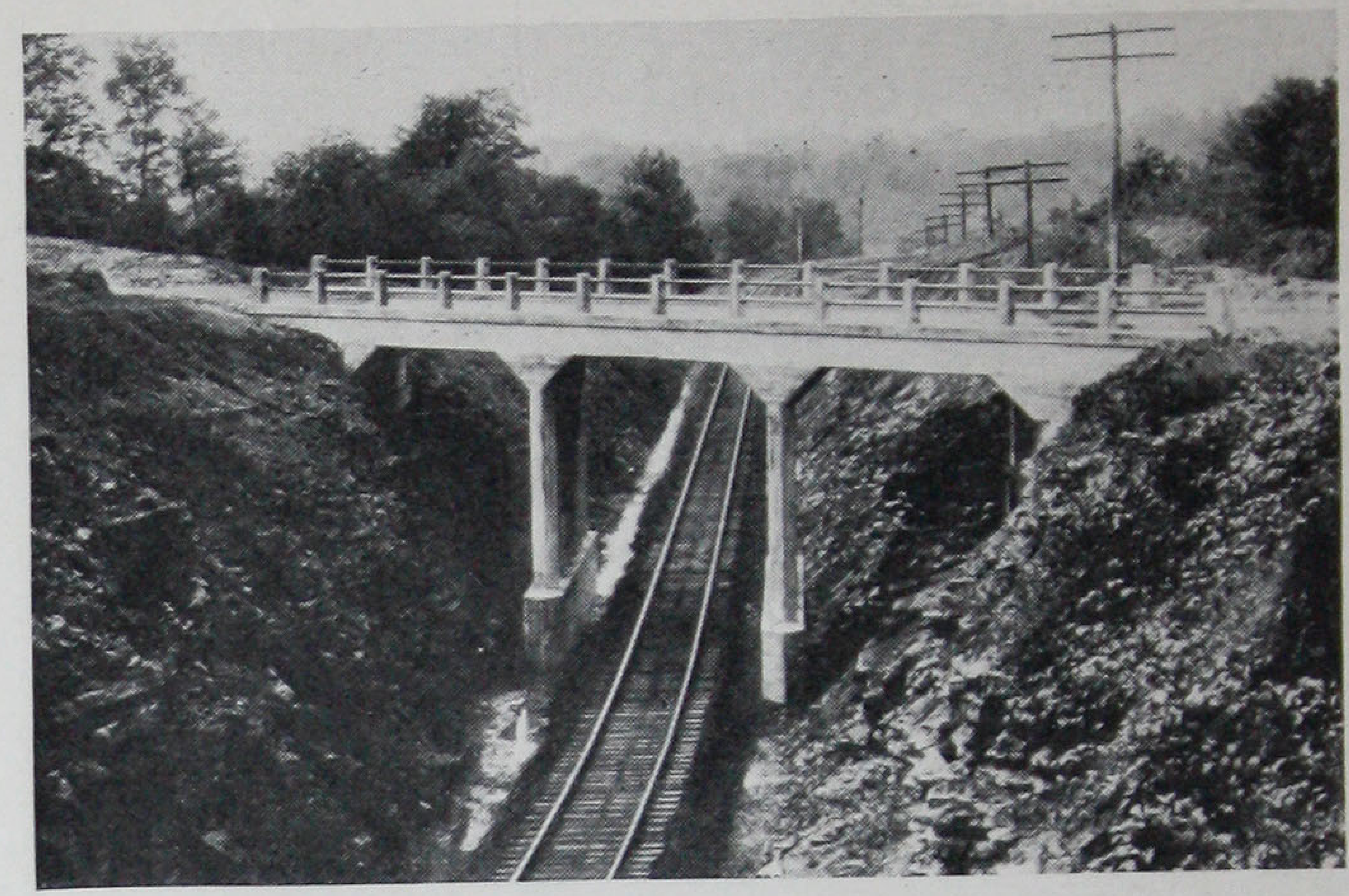
Municipalities Control Concrete

With the great advance in living standards of the American people, there has been an immense program of construction, involving not only street widening and pavements to facilitate traffic but new waterworks, sewage dis-

Sanger Brothers Garage, Dallas, Texas. Reinforced concrete garage of ramp type having capacity of 500 cars. J. A. Pitzinger, Architect, specified water-cement ratio control on this structure as he has done on all work of his office for several years.

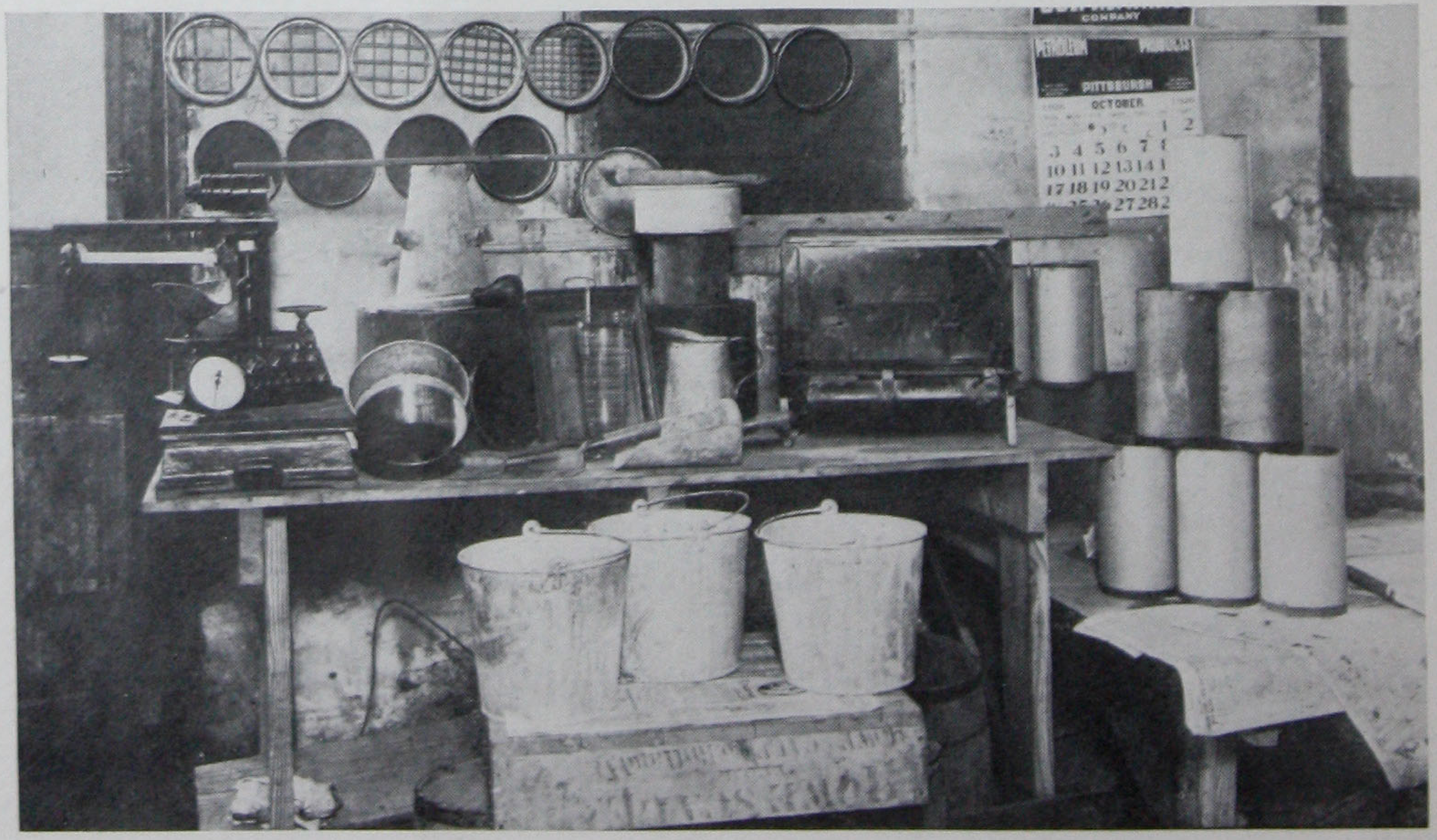
posal plants, administrative buildings of all kinds and other developments for the comfort, health and convenience of the public. These projects involve large volumes of concrete and endurance is one of its most important requirements. Many of the structures must be watertight and in these cases this feature is more important than the strength of the material.

Engineers responsible for the construction of these public improvements have been alert to the many advantages of properly controlling the fabrication of their materials and have used the best methods for concrete control on many projects. In the construction of its river-front improvement, the two-level Wacker Drive, Chicago obtained most excellent results by enforcement of the specification which limited the mixing water to exact amounts. St. Louis is one of the leaders in quality control, using modern methods in the construction of the buildings for its new civic center, such as the Civil Courts Building. The Municipal Service Building, the Howard Bend Pumping and Filtration Plant and other improvements have also been constructed under the water-cement ratio specification. The continued use of these methods on new projects is ample proof of the satisfactory results which have been obtained.



One of the grade separation structures on the Buffalo, Rochester and Pittsburgh Railroad, on which the water-cement ratio specification was used. No job is too large or too small for proper control of quality since the process is so simple.

Pittsburgh has built a number of bridges and structures for their waterworks and is now building the Boulevard of the Allies under similar specifications. Detroit is using careful control methods in the construction of its concrete water tunnels, of which it has a large program and on the new suspension bridge to connect Detroit with Windsor, Canada. A new city hall of classic design was built in Duluth, Minn., and Pasadena, Calif., has completed her new beautiful city hall of the Mediterranean type of architecture. The water-cement ratio specification governed the construction of both these buildings, while similar provisions are used by Minneapolis on the new Cedar Ave.



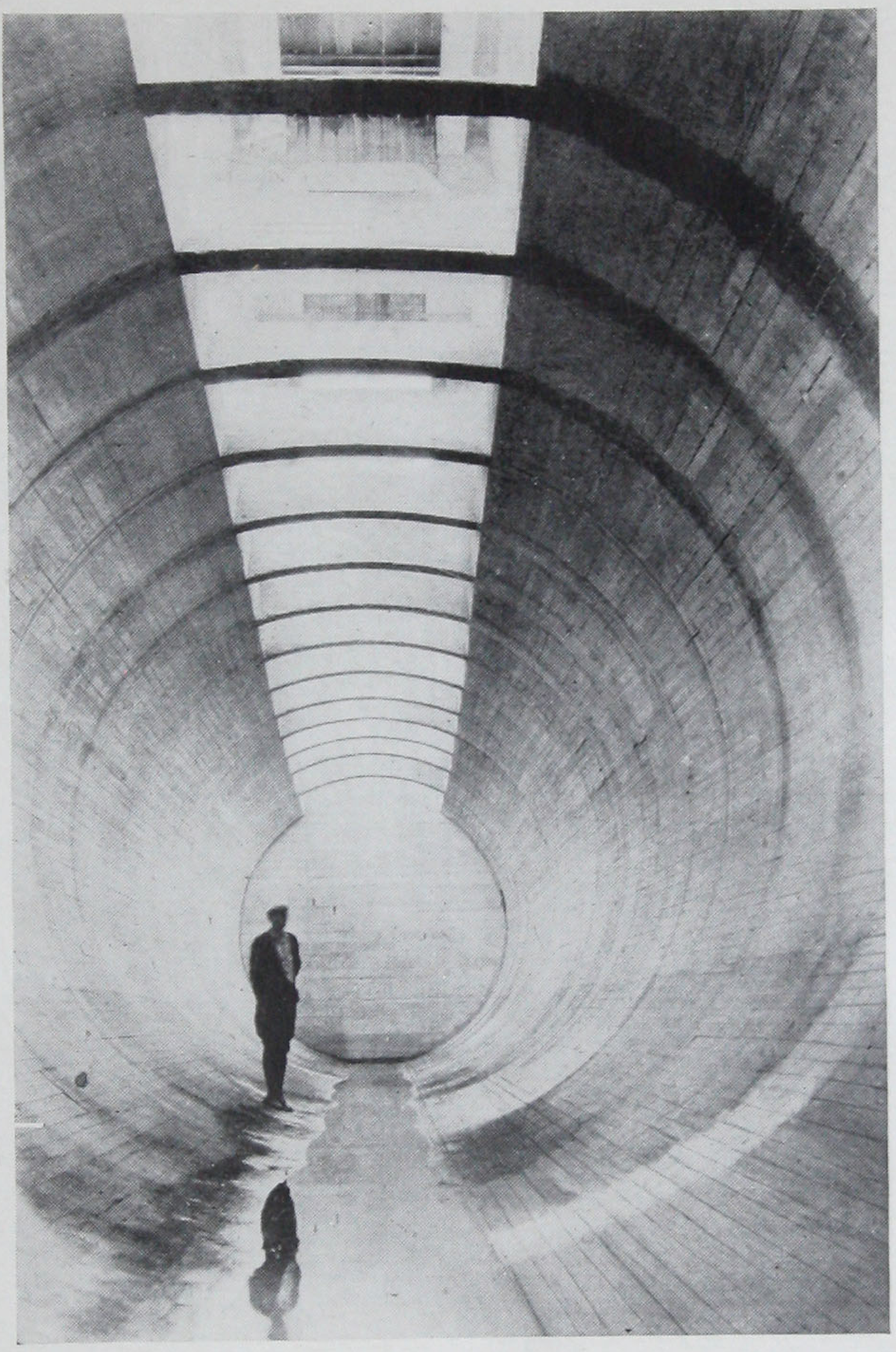
Testing laboratory used during the construction of the Millvale Avenue Bridge in Pittsburgh, Pa. The amount of equipment required will depend on the extent of control desired. In this case the aggregates were studied for grading and were dried in an oven to determine moisture content. The consistency of concrete was measured by the slump cone. Concrete test cylinders were cast in cardboard cylinder molds.

Bridge, by Indianapolis on the construction of a large reservoir and by Portland, Oreg., on the Bull Run River Dam being built by the Water Department.

Flexibility Is Great Advantage

One of the most interesting features of the water-cement ratio method of quality control is its flexibility by which the mix may be readily changed to allow for different conditions of placing or for differences in the characteristics of the materials. On nearly every job there are some parts of thin section with considerable quantities of reinforcement and other parts of heavy section with little reinforcement. While a fairly stiff mix may be used in the latter case, the former calls for a much more plastic mix of better workability.

The proportions of the materials may be easily varied to meet these two conditions. The changes may be only in the proportions of fine to coarse aggregate or they may affect the total volume of aggregate used with each unit of cement. By keeping the ratio of water to cement constant these changes may be made without sacrificing the quality. Under former methods more mixing water was usually added to facilitate placing in difficult locations, often resulting in concrete of totally inadequate quality to withstand the conditions to which it was subjected.



Lake Chelan hydro-electric development, Washington Water Power Co., Washington. This project includes a control dam and intake, power house and two miles of concrete-lined tunnel 14 ft. in diameter, involving a total of 125,000 cu. yd. of concrete. Four classes of concrete having average strengths of 2000, 2500, 3000 and 3500 lb. per sq. in. at 28 days were specified, with mixes designed by control of the water-cement ratio. Sieve analyses of the aggregates were made each day. A total of 4500 test specimens were made and tested in the field laboratory, equipped with a 200,000-lb. testing machine. Almost without exception a very uniform concrete was produced and the actual strengths approached the predetermined strength very closely as shown by the following table:

Design Strength Lb. per sq. in. at 28 days	Average of Field Specimens Lb. per sq. in. at 28 days
3500	3514
3000	3022
2500	2462
2000	1997

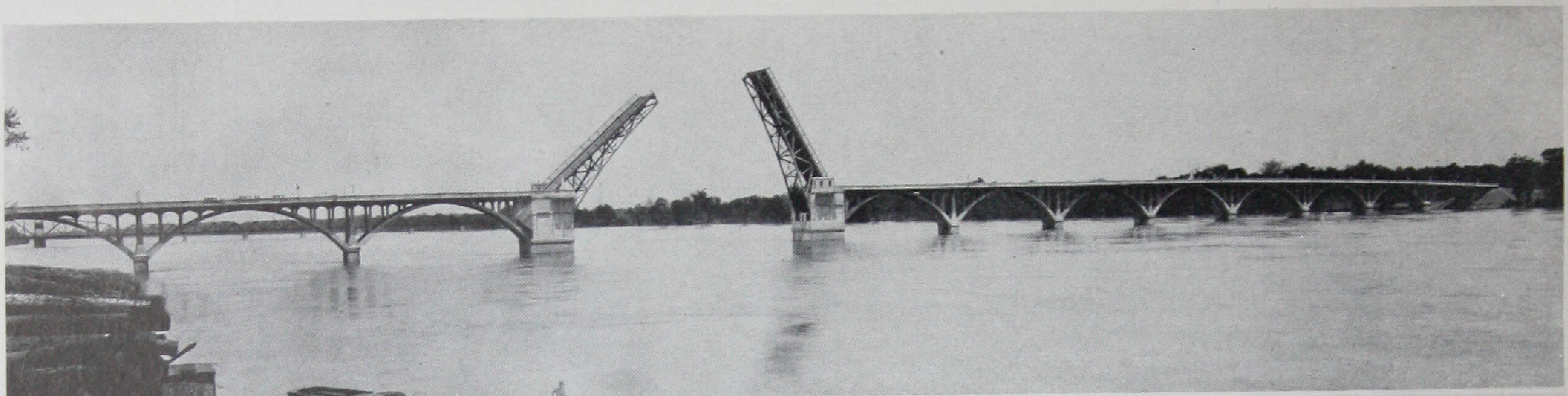
The work was in charge of V. H. Greisser, Chief Engineer of the Washington Water Power Company, and A. M. Philleo was in charge of concrete control.

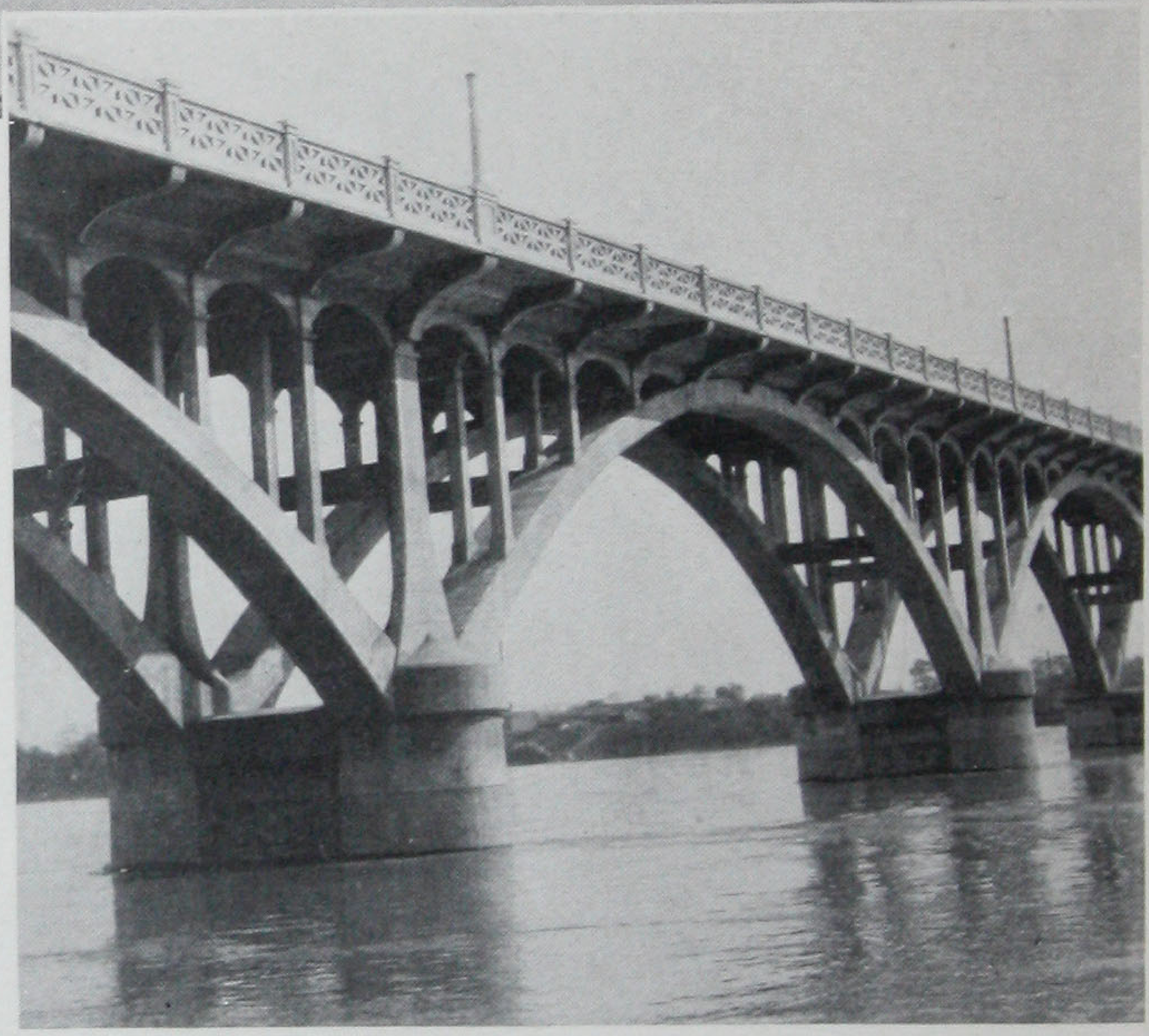
It is extremely desirable to have uniformly graded materials of similar characteristics for the proper control of concrete mixtures. Varying quantities of mixing water have often been used in an endeavor to compensate for variations in aggregates, but again this may result in concrete of inadequate quality where the best is needed. Definite proportions of cement and water will result in definite quality, while the proportions of aggregates may be changed from time to time to allow for variations in grading.

The Time Element

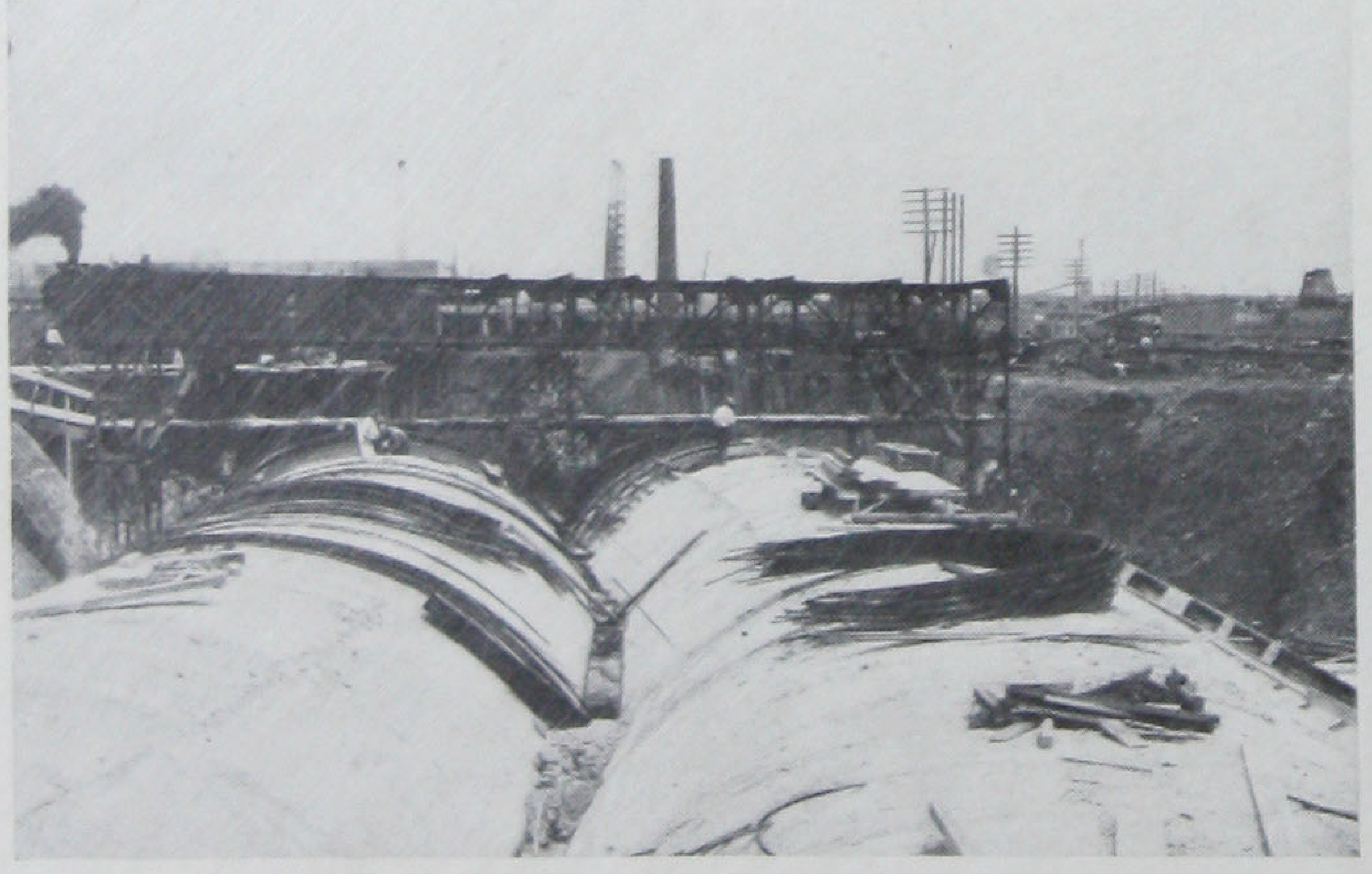
Never has there been a period in history when the element of time was more important. It is true that the cost of labor is high, but with modern equipment it is also efficient, and it is therefore necessary to use materials efficiently.

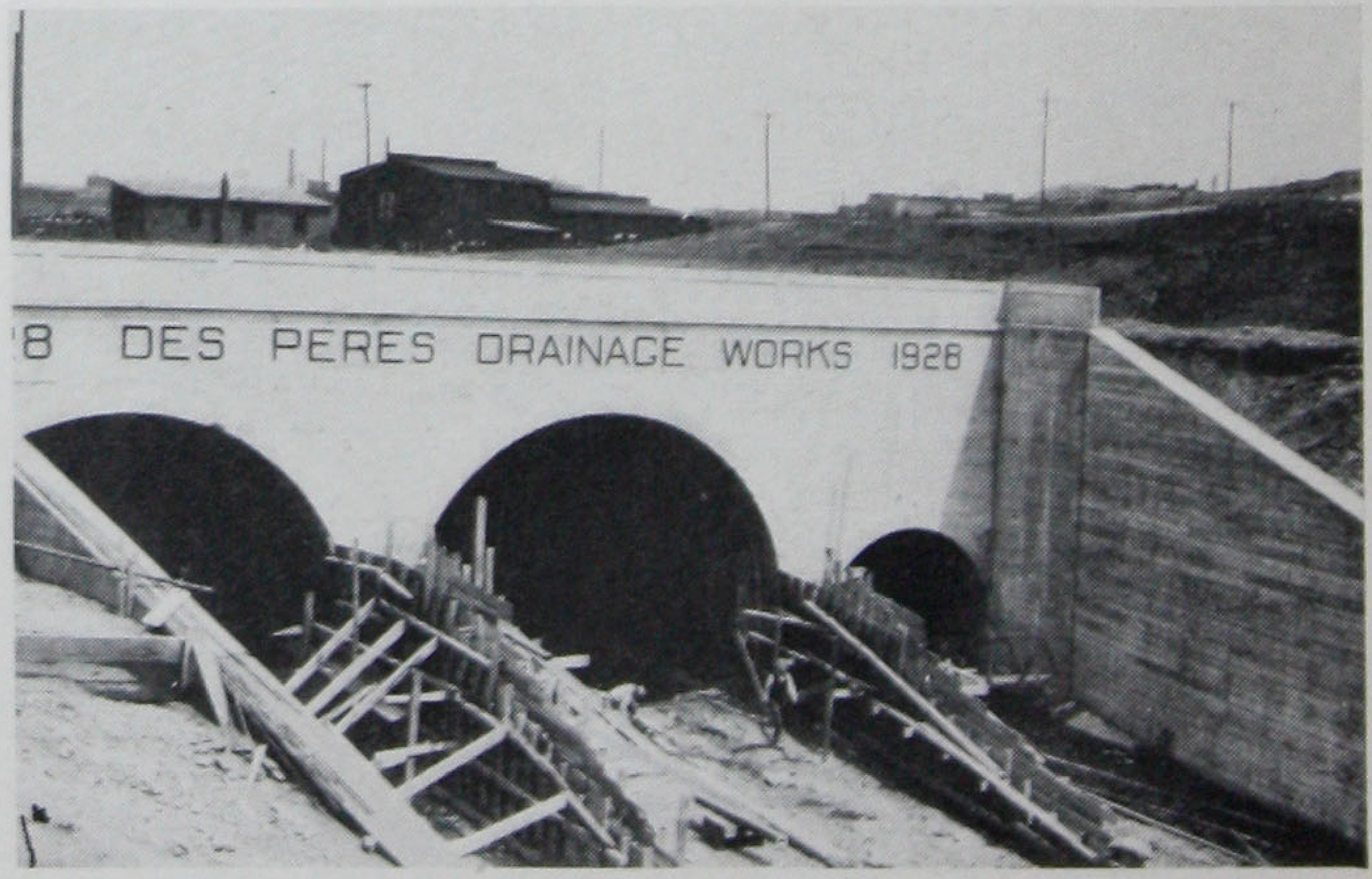
In modern building construction, which is usually of the multi-story type, the speed of construction is extremely rapid. With a well-





Keller Memorial Bridge, Decatur, Alabama. This is one of the most important links in the highway system of Alabama. When construction operations started a complete field laboratory to test and control the quality of the materials was set up. Trial batches were made until mixtures of the desired workability were obtained for each of the three classes of concrete specified. Two sizes of coarse aggregate, ranging in size from $\frac{1}{4}$ to $\frac{3}{4}$ and $\frac{3}{4}$ to $1\frac{1}{2}$ inches, were used. This proved very convenient to produce uniform batches exactly suited for their respective places in the structure. Test cylinders were made daily. The appearance of the structure is exceptionally fine, free from the blemishes that too often occur under improper methods of proportioning. H. H. Houk is Bridge Engineer of the Alabama Highway Department, Paul Moller was in charge of design, and J. L. Land was in charge of inspection and field work. Their work has produced a structure that will stand indefinitely as a memorial to William Simpson Keller, first Chief Engineer of the Alabama Highway Commission, to the memory of whom this bridge is dedicated.

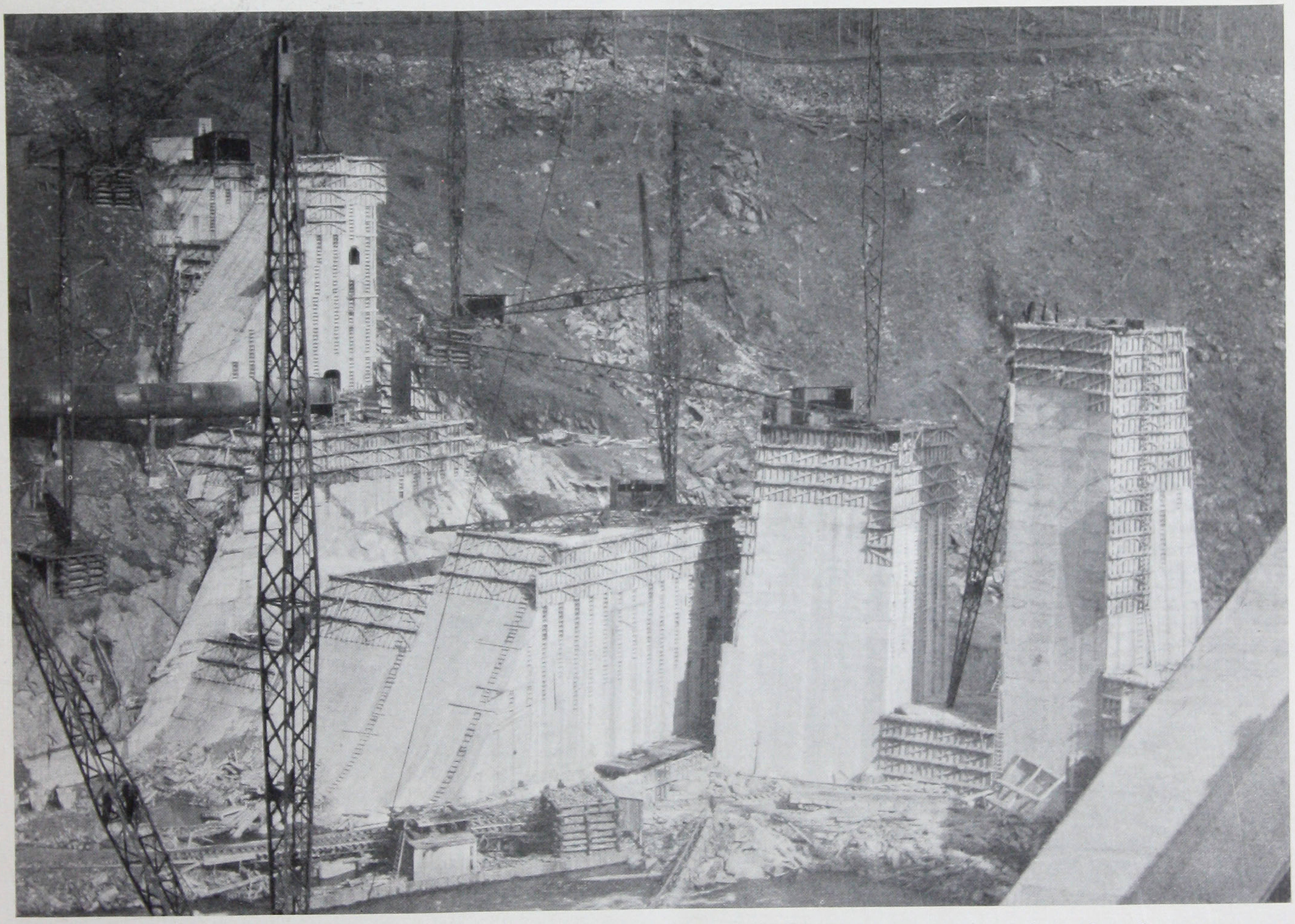




River des Peres drainage sewer project, St. Louis, Mo. This project consists of concrete-lined channels and concrete tunnels over a total length of 13 miles. The tunnels are 29 feet wide and 23 feet high inside. Watertight concrete was required and was more important than strength. The specifications called for 6 sacks of cement per cubic yard of concrete and 55 pounds of water to a sack of cement. With this combination, concrete of good workability to facilitate placing was obtained and the tests indicated high strengths. It was also specified that forms were not to be removed until a strength of 1200 lb. per sq. in. had been attained. Test cylinders were therefore broken at 3, 5, 14, and 28 days, which not only served as a check on the strength of concrete but indicated to the contractor when the forms could be removed. An inundator was used for measuring the sand and water. The grading of the aggregates was very uniform as demonstrated by the sieve analyses tests which were made at intervals. The work is under the direction of the Board of Public Service, Division of Sewers and Paving, W. W. Horner, Chief Engineer.

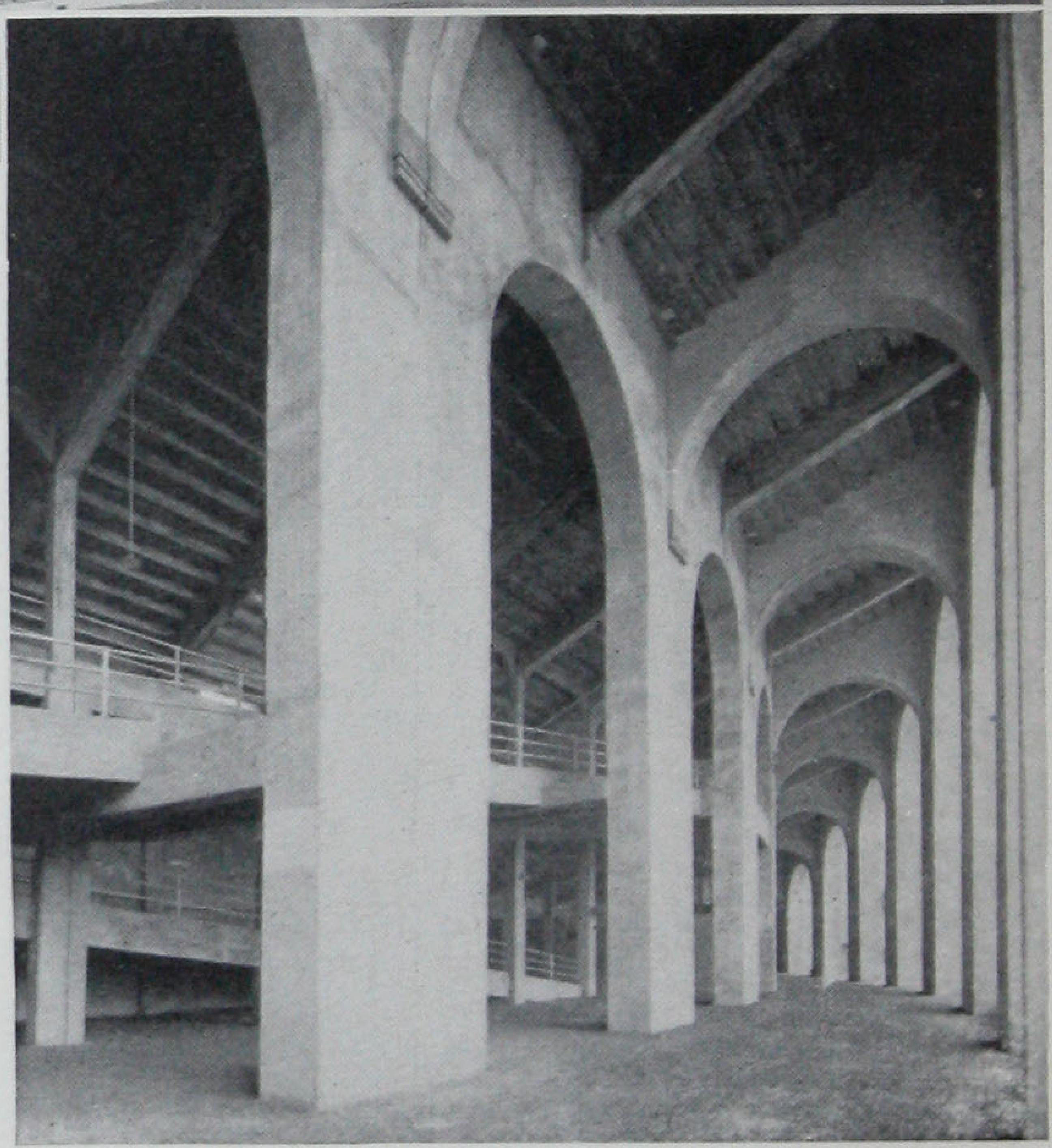
designed mix, properly controlled, the placing of the concrete is made easier, thus assisting to keep up the construction schedule. The concrete in the lower stories must be supported until it has attained sufficient strength to withstand the weight of the materials and the construction loads imposed.

To prevent delay and also to save on form work and supporting timbers, many contractors have found it profitable to use low water-cement ratios and richer mixes, resulting in concrete of high strength at early ages. This permits early removal of forms and supports, with a consequent saving in quantity required. It also makes it possible to proceed more rapidly with other construction operations. Capital is tied up for shorter periods, and, since the building can be put into use at an earlier date,

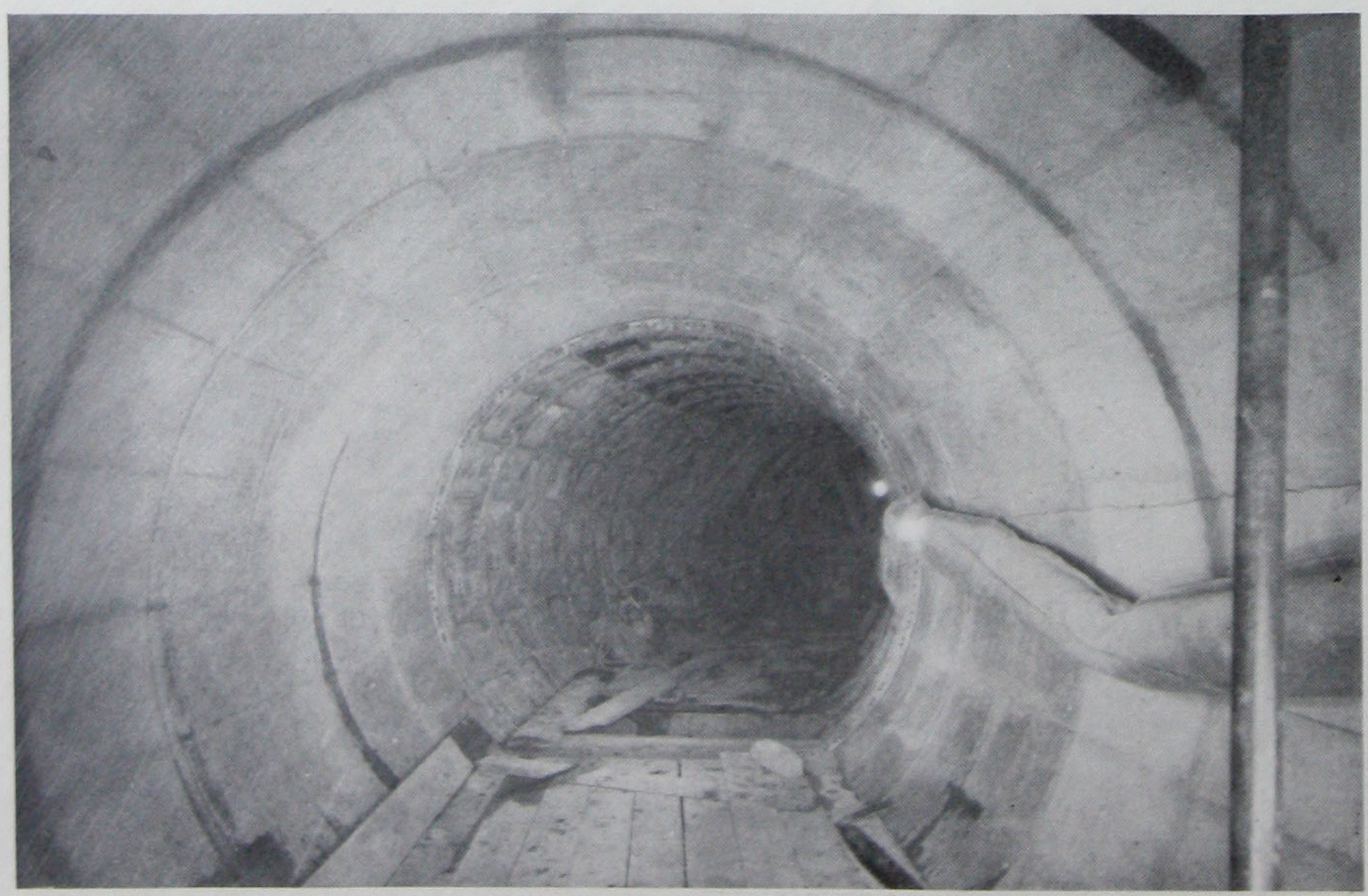


The Santeetlah dam and power project near Calderwood, Tennessee, involved 249,000 cu. yd. of concrete placed by the construction forces of the Tallassee Power Co. All aggregate was prepared at a nearby quarry, crushing the stone to the desired sizes, ranging up to eight inches. Due to difficulties encountered in crushing to a uniform grading, it was decided that some scheme of mixture design would have to be formulated to permit rapid adjustment of aggregate quantities based on visual inspection at the measuring hoppers. It was decided to design mixes on the basis of water-cement ratio and proportion aggregate quantities to produce the desired workability. This temporary expedient, intended for use until the necessary adjustments could be made in the plant to produce more uniform aggregates, proved successful and on account of its simplicity was adopted as the permanent procedure. Specifications called for concrete having strengths of 2000 and 2500 lb. per sq. in. at 28 days with minimum strengths of 1700 and 2000 lb. per sq. in. respectively and not more than 25 per cent of the test specimens below the average. Practically all tests showed values higher than minimum requirements.

The approximate cost of inspection and testing was 4.65 cents per cubic yard, including testing about 325,000 barrels of cement, which was the larger portion of the expense and would have been incurred under any method of control. Samples from each lift of each block were taken and totaled about 6000 8 by 16-inch cylinders. Aggregate larger than 2½ inches was removed from the concrete before forming test specimens.



Dyche Stadium, Northwestern University, Evanston, Illinois. Because large areas of the concrete were to be exposed to severe weathering conditions it was essential that concrete of the requisite density to resist this action be obtained. To add speed incentive to the undertaking, a clause in the contract called for a penalty for each seat that the contractor did not have ready at the prescribed time. Two classes of concrete having strengths of 2000 and 3000 lb. per sq. in. were required. Mixes were carefully designed and controlled. When it was found that more speed was required to avoid a penalty the mixes were redesigned to produce higher strengths at early ages. This allowed the earlier removal of forms and shoring and facilitated placing and finishing. The amount of mixing water was reduced from 7½ to 6 gal. per sack of cement. This change cut the time required for shoring more than 50 per cent and allowed finishing of the structure in the prescribed time. James Gamble Rogers, Architect; Gavin Hadden, Engineer; J. B. French Company, Contractors.



Water Tunnels at Detroit, Mich. In planning nearly ten miles of undercity tunneling for the additional water supply of Detroit, particular care was taken to provide for engineering control of construction. These tunnels are being built of concrete at depths of 60 to 110 feet below the street surface. They are 12 and 14 feet in inside diameter. The amount of mixing water was placed at 6½ gal. maximum per sack of cement.

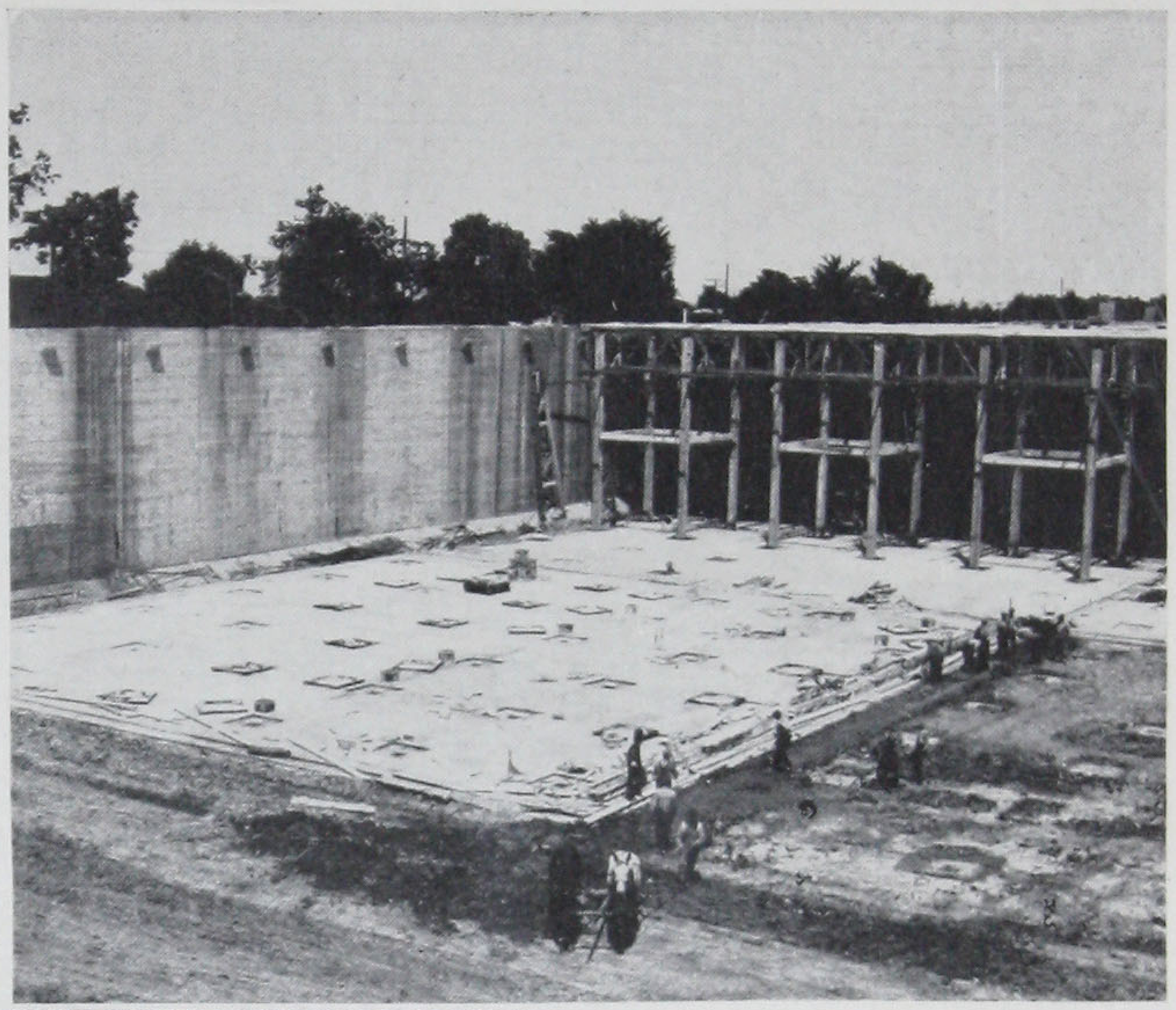
Under the conditions of placement, a wide range in consistency is necessary—a wet, flowing mixture to get the concrete in the invert and a dry mixture for shoveling into the crown. A report issued when about 3 miles had been completed indicated high and uniform results. George H. Fenkel, Chief Engineer. L. G. Lenhardt and Torris Eide, Assistant Engineers.

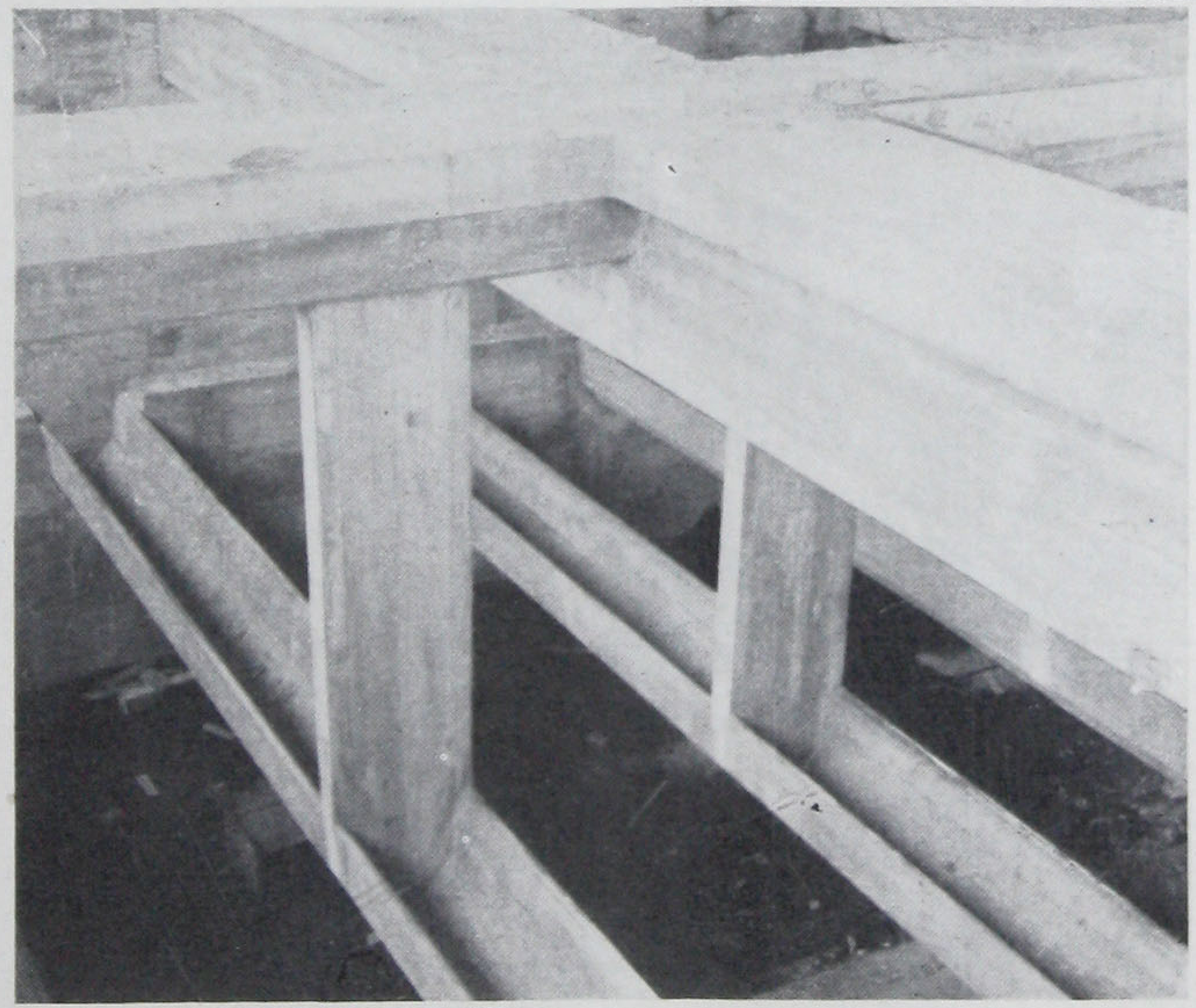
a saving is made by the owner in carrying charges.

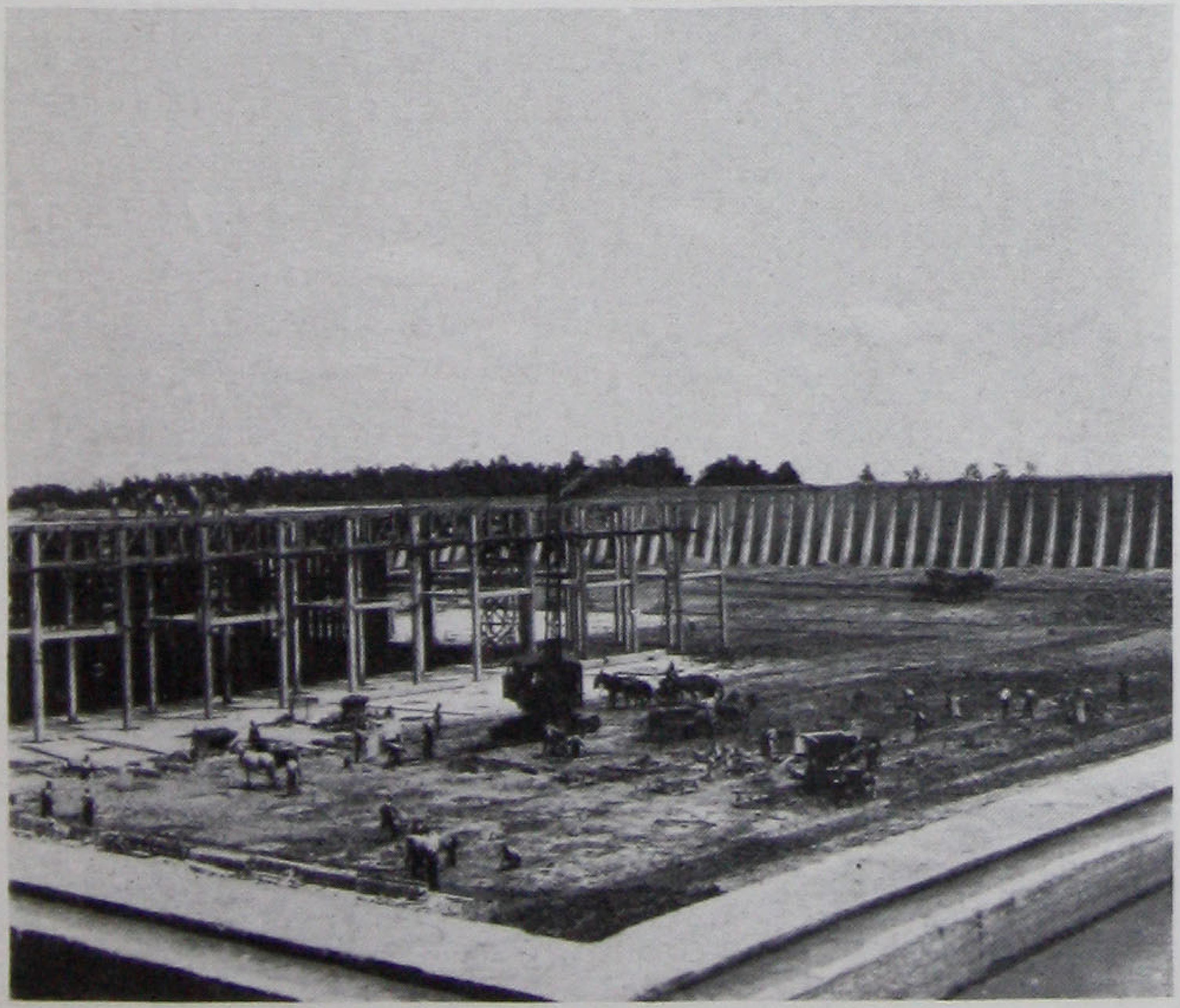
Higher Stresses May Be Used

Modern conditions demand the elimination of waste and the full utilization of all materials. Under the haphazard methods of making concrete in the past, no provision was made in the commonly accepted design practice for concrete having strength higher than 3000 lb. per sq. in. In the past decade there has been a gradual improvement in the quality of portland cement and this fact, coupled with the knowledge that has been acquired as to the effect each factor has in concrete making, makes it practicable to proportion and use concrete of much higher strength.

This has been recognized in the report of Committee E-1 of the American Concrete Institute in its "Tentative Building Regulations for Reinforced Concrete" submitted at the annual convention in February, 1928. These regulations permit the basing of strength on the results of field tests and allow corresponding values for stress.







Stacey Park Reservoir, St. Louis, Mo. As in other public works in St. Louis the mixes for this plant were carefully designed from a study of the available materials and then controlled throughout the job. A consideration of the concrete from the standpoint of watertightness was more important than strength. An inundator was used to measure the sand and mixing water. Test specimens were broken at various ages. John C. Pritchard, Director of Public Utilities; Leonard A. Day, Water Commissioner.

The higher strengths are easily obtained, but if they are to be depended upon and used in design it is essential that each operation in the making and placing of concrete is properly controlled. Only by such control can the material be used to the best advantage of all concerned.

In Conclusion

As the use of specifications providing for better control of concrete based on the water-cement ratio principle increases, additional advantages are found from time to time. In general, however, the advantages of this method may be summarized in the following items:

Concrete of definite strength to meet the requirements of the project may easily be obtained.

Concrete that is durable and will withstand weathering conditions may be assured.

Watertight concrete may be made that will resist high pressures.

Proportions of materials may be adjusted to give workability suitable for the work at hand.

Easier placement is possible on account of the better workability. Less labor is therefore required, and finishing is facilitated.

Segregation may be avoided by using concrete of proper workability, thus avoiding weak planes which may be porous and subject to attack by destructive elements.

Quick adjustments may be made in the proportions to facilitate placing where different consistencies are required. This may be done without changing the quality of the concrete.

High strength at early ages may be produced to reduce time of construction and quantity of form work.

Higher stresses may be used, thereby, utilizing the materials more effectively.

Most of these advantages produce more economical results.

Concrete road construction near Murfreesboro, Tenn. The highway department of Tennessee fixes the amount of water that may be used per unit of cement, thus assuring the strength required for the increasing volume of traffic. With mechanical finishing machines, a rather stiff mix can be used so that high strength can be developed economically.

City Hall, Pasadena, California. The construction is reinforced concrete with monolithic concrete walls covered with colored portland cement stucco. All ornamental features are concrete. Much of the interior wall surface is also decorated with portland cement stucco. The structure required about 19,000 cu. yd. of concrete, designed for compressive strength of 2000 lb. per sq. in. at 28 days. Concrete of uniformly high quality was produced by careful water control. In an article in the December, 1927, issue of Concrete Highways and Public Improvements Magazine, Mr. Harvey W. Hincks, Engineer in charge of construction, says: "Over 300 test cylinders were made and none tested below the minimum. The average for all concrete was 1700 lb. at 7 days and 2800 lb. at 28 days. Concrete of this character was produced at no additional cost through careful control of the factors affecting the strength and workability."

BUILDING CODES THAT SPECIFY WATER-CEMENT RATIO

Alhambra, Calif.
Beaumont, Texas
Blairsville, Pa.
Coronado, Calif.
Dallas, Texas
Dayton, Ohio
Des Moines, Iowa
Eldorado, Ark.
Elkhart, Indiana
El Monte, Calif.
Eugene, Oreg.
Fontana, Calif.
Fort Worth, Texas
Fresno, Calif.
Hatboro, Pa.
Indianapolis, Ind.
Kansas City, Kans.
Klamath Falls, Ore.
Laguna Beach, Calif.
Meridian, Miss.
Monroe, La.
Morristown, N. J.
Mount Vernon, N. Y.
Oceanside, Calif.
Ontario, Calif.
Piedmont, Calif.
Pomona, Calif.
Port Arthur, Texas
Redlands, Calif.
Sacramento, Calif.
San Bernardino, Calif.
San Jose, Calif.
San Rafael, Calif.
Shreveport, La.
Springfield, Mass.

RAILROADS USING WATER-CEMENT RATIO SPECIFICATIONS

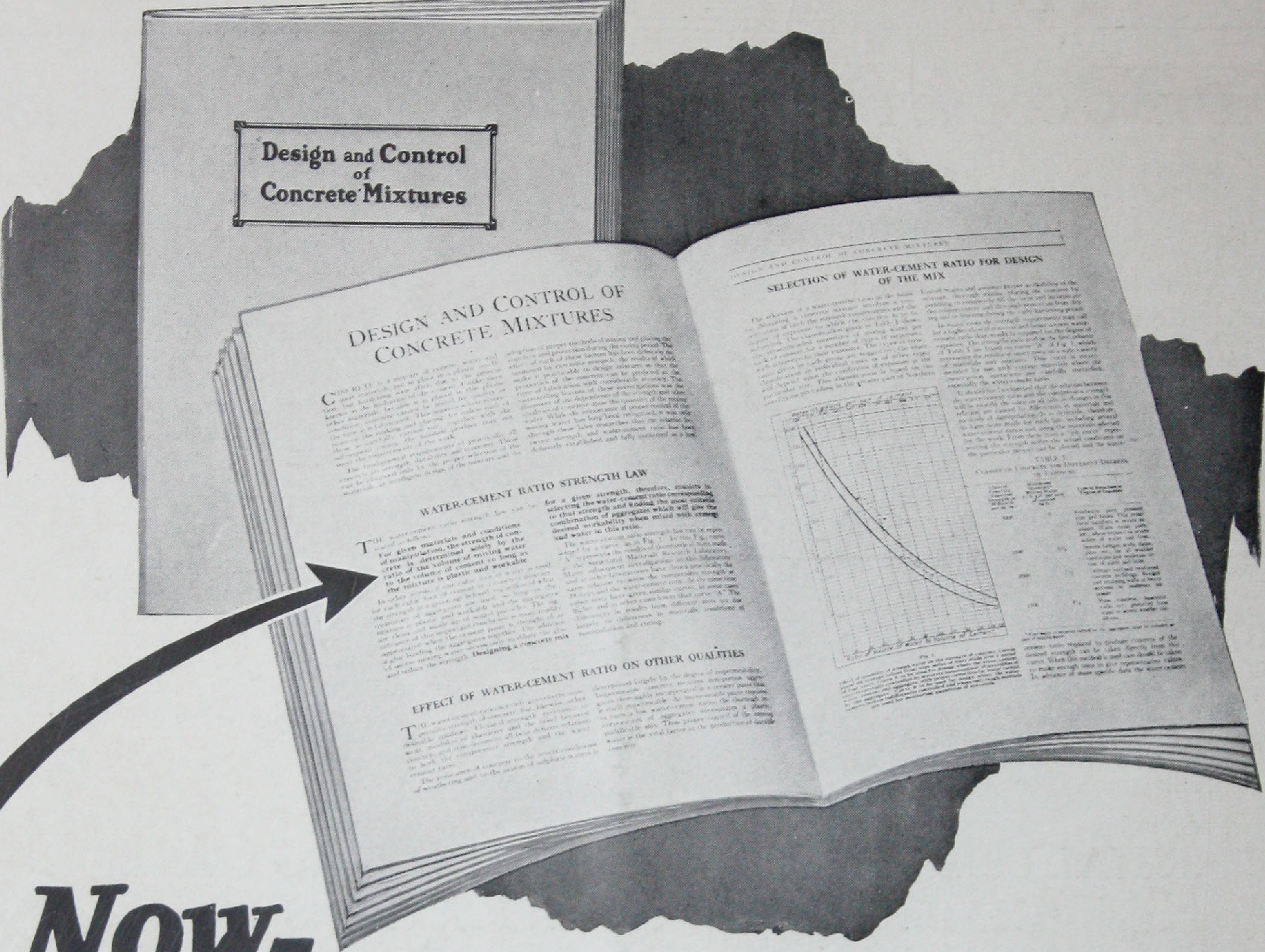
Atchison, Topeka & Santa Fe Railway
Baltimore & Ohio Railroad
Boston & Maine Railroad
Buffalo, Rochester & Pittsburgh Railway
Canadian National Railways
Chesapeake & Ohio Railway
Chicago & Eastern Illinois Railway Co.
Chicago & Northwestern Railway
Chicago & Western Indiana Railroad
Chicago, Burlington & Quincy Railroad
Chicago, Milwaukee, St. Paul & Pacific Railroad
Cleveland, Cincinnati, Chicago & St. Louis Ry.
Duluth & Iron Range Railroad Co.
Erie Railroad
Great Northern Railway
Minneapolis, St. Paul & Sault Ste. Marie Railway
New York, Chicago & St. Louis Railroad Co.
Norfolk & Western Railway
Southern Railway
Union Pacific Railroad

PARTIAL LIST OF PUBLIC UTILITIES USING WATER-CEMENT RATIO SPECIFICATIONS

Alabama Power Co., Birmingham, Ala.
Columbia Gas & Electric Co., Cincinnati, Ohio
Consumers Power Co., Kalamazoo, Mich.
Detroit Edison Co., Detroit, Mich.
Erie Lighting Co., Erie, Pa.
Hydro-Electric Power Commission of Cntario, Toronto, Ont., Can.
Illinois Bell Telephone Co., Chicago, Ill.
Jefferson Power & Light Co., Jefferson, N. C.
Kentucky Hydro-Electric Co., Chicago, Ill.
S. W. Bell Telephone Co., Dallas, Texas
Stone & Webster, Inc., New York City
Tallassee Power Co., Calderwood, Tenn.
Washington Gas Light Co., Washington, D. C.
Western Electric Co., Kearny, N. J.
Wisconsin Power & Light Co., Madison, Wisc.
Wisconsin Telephone Co., Milwaukee, Wisc.

THESE MUNICIPALITIES SPECIFIED WATER-CEMENT RATIO

Albuquerque, N. M.	Waterworks
Altus, Okla.	Lugert Dam
Bloomington, Ill.	Sewage Disposal Plant
Boulder, Colo.	Paving
Buffalo, N. Y.	Bridges
Chicago, Ill.	Wacker Drive
Cumberland, Md.	Flood Control Works
Dallas, Texas	Municipal Auditorium
Denton, Texas	City Hall
Detroit, Mich.	Detroit-Windsor Bridge, Water Tunnels
Duluth, Minn.	City Hall
Durham, N. C.	Sewage Disposal Plant
Emporia, Kans.	Paving
Evanston, Ill.	Paving
Falmouth, Mass.	Green Pond Bridge
Gaithersburg, Md.	Sewage Disposal Plant
Grand Rapids, Mich.	Sewage Disposal Plant
Green Bay, Wisc.	West Senior High School
Harlingen, Texas	Power Plant
Hickory, N. C.	Paving
Highland Park, Texas	Fire Station
Independence, Kans.	Paving
Indianapolis, Ind.	Park Buildings, Water Reservoir, Garage
Jennings, La.	Paving
Kemmerer, Wyo.	Paving
Kenmore, Ohio	Sewage Disposal Plant
Kinston, N. C.	Water Reservoir
Lawrence, Kans.	Paving
Mansfield, Ohio	Water Reservoir
Milwaukee, Wisc.	Paving, Schools, Bridge
Minneapolis, Minn.	Bridges
Muskegon, Mich.	Paving
New Orleans, La.	Wharves
Newton, N. C.	Waterworks
New York, N. Y.	Bridges, Park Structures
Pittsburgh, Pa.	Bridges, Paving, Water Reservoir
Portland, Oreg.	Bull Run River Dam
Saginaw, Mich.	Waterworks
St. Louis, Mo.	Civil Courts Building, Municipal Service Building, Waterworks, and Sewers
Salina, Kans.	Paving
San Antonio, Texas	Almos Creek Dam
Springfield, Ill.	Sanitary District
Springfield, Mo.	Grant Avenue Viaduct
Virginia Beach, Va.	Seawall & Beachwalk
Waukegan, Ill.	Water Reservoir
Wauwatosa, Wisc.	School
Wichita Falls, Texas	Municipal Auditorium
Wyandotte, Mich.	Paving



Design and Control of Concrete Mixtures

DESIGN AND CONTROL OF CONCRETE MIXTURES

WATER-CEMENT RATIO STRENGTH LAW

EFFECT OF WATER-CEMENT RATIO ON OTHER QUALITIES

SELECTION OF WATER-CEMENT RATIO FOR DESIGN OF THE MIX

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This booklet, "Design and Control of Concrete Mixtures," emphasizes the importance of water-cement ratio on the qualities of concrete—such as strength, watertightness, and durability. Selection of materials, estimation of quantities, importance of curing, and control of concrete in the field are discussed. For your free copy of this practical aid, address our nearest District Office.

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A National Organization to Improve and Extend the Uses of Concrete

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